Limnology of Blue Mesa, Morrow Point, and Crystal Reservoirs, Curecanti National Recreation Area, during 1999, and a 25-Year Retrospective of Nutrient Conditions in Blue Mesa Reservoir, Colorado

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FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources. (http://www.usgs.gov/). Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity *and* quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. (http://water.usgs.gov/nawqa). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units. (http://water.usgs.gov/nawqa/nawqamap.html). Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings. (http://water.usgs.gov/nawqa/natsyn.html).

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Associate Director for Water

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per day (acre-ft/d)	0.01428	cubic meter per second
centimeter (cm)	0.3937	inch
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter (m)
gallon (gal)	3.785	liter (L)
inch	25.4	millimeter
liter (L)	0.2642	gallon (gal)
kilogram (kg)	2.205	pound, avoirdupois
kilograms per day (kg/d)	2.205	pounds, avoirdupois per day
meter (m)	3.2808	foot (ft)
milliliter (mL)	2.642×10^{-4}	gallon (gal)
mile (mi)	1.609	kilometer

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F = 1.8 (°C) + 32

Additional Abbreviations

algal units/L	algal units per liter
Curecanti NRA	Curecanti National Recreation Area
E	estimated
LT-MDL	long-term method detection level
LRL	laboratory reporting level
mg/m^3	milligrams per cubic meter
mg/L	milligram(s) per liter
MRL	minimum reporting level
NAWQA	National Water-Quality Assessment
N:P	nitrogen:phosphorus
NWQL	National Water Quality Laboratory
TSI	trophic-state index
UCOL	Upper Colorado River Basin Study Unit
µm	micrometer
µS/cm	microsiemens per centimeter at 25 degrees Celsius
USEPA	U.S. Environmental Protection Agency
WY	water year (a 12-month period beginning October 1 and ending September 30 of the following year. A water year is described by the year in which it ends.)

Limnology of Blue Mesa, Morrow Point, and Crystal Reservoirs, Curecanti National Recreation Area, during 1999, and a 25-Year Retrospective of Nutrient Conditions in Blue Mesa Reservoir, Colorado

By Nancy J. Bauch *and* Matt Malick

Abstract

The U.S. Geological Survey and the National Park Service conducted a water-quality investigation in Curecanti National Recreation Area in Colorado from April through December 1999. Current (as of 1999) limnological characteristics, including nutrients, phytoplankton, chlorophyll-*a*, trophic status, and the water quality of stream inflows and reservoir outflows, of Blue Mesa, Morrow Point, and Crystal Reservoirs were assessed, and a 25-year retrospective of nutrient conditions in Blue Mesa Reservoir was conducted. The three reservoirs are in a series on the Gunnison River, with an upstream to downstream order of Blue Mesa, Morrow Point, and Crystal Reservoirs. Physical properties and water-quality samples were collected four times during 1999 from reservoir, inflow, and outflow sites in and around the recreation area. Samples were analyzed for nutrients, phytoplankton and chlorophyll-*a* (reservoir sites only), and suspended sediment (stream inflows only). Nutrient concentrations in the reservoirs were low; median total nitrogen and phosphorus concentrations were less than 0.4 and 0.06 milligram per liter, respectively. During water-column stratification, samples collected at depth had higher nutrient concentrations than photic-zone samples. Phytoplankton community and density were affected by water temperature, nutrients, and water residence time. Diatoms were the dominant phytoplankton throughout the year in Morrow Point and Crystal Reservoirs and during spring and early winter in Blue Mesa Reservoir. Blue-green algae were dominant in Blue Mesa Reservoir during summer and fall. Phytoplankton density was highest in Blue Mesa Reservoir and lowest in Crystal Reservoir. Longer residence times and warmer temperatures in Blue Mesa Reservoir were favorable for phytoplankton growth and development. Shorter residence times and cooler temperatures in the downstream reservoirs probably limited phytoplankton growth and development. Median chlorophyll-*a* concentrations were higher in Blue Mesa Reservoir than Morrow Point or Crystal Reservoirs. Blue Mesa Reservoir was mesotrophic in upstream areas and oligotrophic downstream. Both Morrow Point and Crystal Reservoirs were oligotrophic. Trophic-state index values were determined for total phosphorus, chlorophyll-*a*, and Secchi depth for each reservoir by the Carlson method; all values ranged between 29 and 55. Only the upstream areas in Blue Mesa Reservoir had total phosphorus and chlorophyll-*a* indices above 50, reflecting mesotrophic conditions. Nutrient inflows to Blue Mesa Reservoir, which were derived primarily from the Gunnison River, varied on a seasonal basis, whereas nutrient inflows to Morrow Point and Crystal Reservoirs, which were derived primarily from deep water releases from the respective upstream reservoir, were steady throughout the sampling period. Total phosphorus concentrations were elevated in many

stream inflows. A comparison of current (as of 1999) and historical nutrient, chlorophyll-*a*, and trophic conditions in Blue Mesa Reservoir and its tributaries indicated that the trophic status in Blue Mesa Reservoir has not changed over the last 25 years, and more recent nutrient enrichment has not occurred.

INTRODUCTION

Curecanti National Recreation Area (Curecanti NRA) encompasses three reservoirs on the Gunnison River in west-central Colorado (fig. 1). Blue Mesa, Morrow Point, and Crystal Reservoirs, collectively known as the Wayne N. Aspinall Storage Unit of the Colorado River Storage Project, were created in the 1960’s and 1970’s for water storage, power production, streamflow regulation, and recreation. The primary recreational feature of the Aspinall Unit is the stocked fishery associated with the three reservoirs, which includes kokanee salmon (*Oncorhynchus nerka*), rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), lake trout (*Salvelinus namaycush*), and cutthroat trout (*Oncorhynchus clarki pleuriticus*). Optimal conditions in Blue Mesa Reservoir have made it one of the premier kokanee salmon fisheries in the Western United States, and the fishery-related tourism benefits local economies. A healthy aquatic system is needed for the fishery of Curecanti NRA to continue into the future.

Population growth and land-use changes upstream from Curecanti NRA, as well as reservoir operations and transbasin water diversions, have the potential to affect water quantity and quality and aquatic biology in the three reservoirs. From 1970 to 1998, the population of Gunnison County (fig. 1) increased 76 percent (Colorado Department of Local Affairs, 1999), resulting in substantial land-use changes in the upper Gunnison River Valley because of increased development. Almost 48 percent of the Curecanti NRA boundary abuts private property; many of these properties have proposed development for recreational vehicle campgrounds and single-family homes (National Park Service, 1995). Numerous acres of ranchland are being converted to urban development. Nutrient levels in Blue Mesa Reservoir, as well as in Morrow Point and Crystal Reservoirs, may be affected by these land-use changes. Thermal regimes in the reservoirs and, ultimately, the productivity of the reservoirs also may be adversely affected by potential changes in the operation of the Aspinall Unit reservoirs to meet proposed downstream streamflow requirements for endangered fish. Changes in streamflow caused by reservoir operations and water diversions have altered important habitats and restricted the range of endangered fish and their access to former habitats (Pitlick, 2002). It is not known if or how potential transbasin diversions to meet water needs of the Front Range of Colorado and the final quantification of the National Park Service water right for the Black Canyon of the Gunnison National Park may affect the quantity and quality of water in the three reservoirs.

While numerous reports are available on the water resources of the upper Gunnison River Valley and Curecanti NRA, there is a general lack of recent information, especially nutrient data and nutrient pathways, for the recreation area itself. Intensive limnological studies were conducted on Blue Mesa Reservoir in 1975 and 1982–85, but no recent intensive investigations pertaining to nutrients in the reservoir have been done. Few studies have been done on the limnology of Morrow Point and Crystal Reservoirs. For all but the major inflow streams, little or no physical, chemical, or hydrologic data are available. Very little information is available on nutrient concentrations in discharges from Blue Mesa and Morrow Point Dams.

Nutrients are of prime importance in the maintenance of the fisheries and aquatic systems of the three reservoirs. Over the last 25 years, several studies of the limnology of Blue Mesa Reservoir (U.S. Environmental Protection Agency, 1977; Cudlip and French, 1985) have called for continued investigations into nutrient enrichment of the Aspinall Unit. The water-resources planning document for Curecanti NRA (Cudlip and others, 1996) recognized the importance of biological productivity in the reservoirs in meeting the needs of native and stocked fish; however, up-to-date information on nutrient inflows and outflows and productivity of the three reservoirs generally is limited. Finally, recent concerns of additional nutrient loading from upstream sources because of land-use changes indicated a need to compare data describing ambient conditions in Blue Mesa Reservoir to data from the 1970’s and 1980’s.

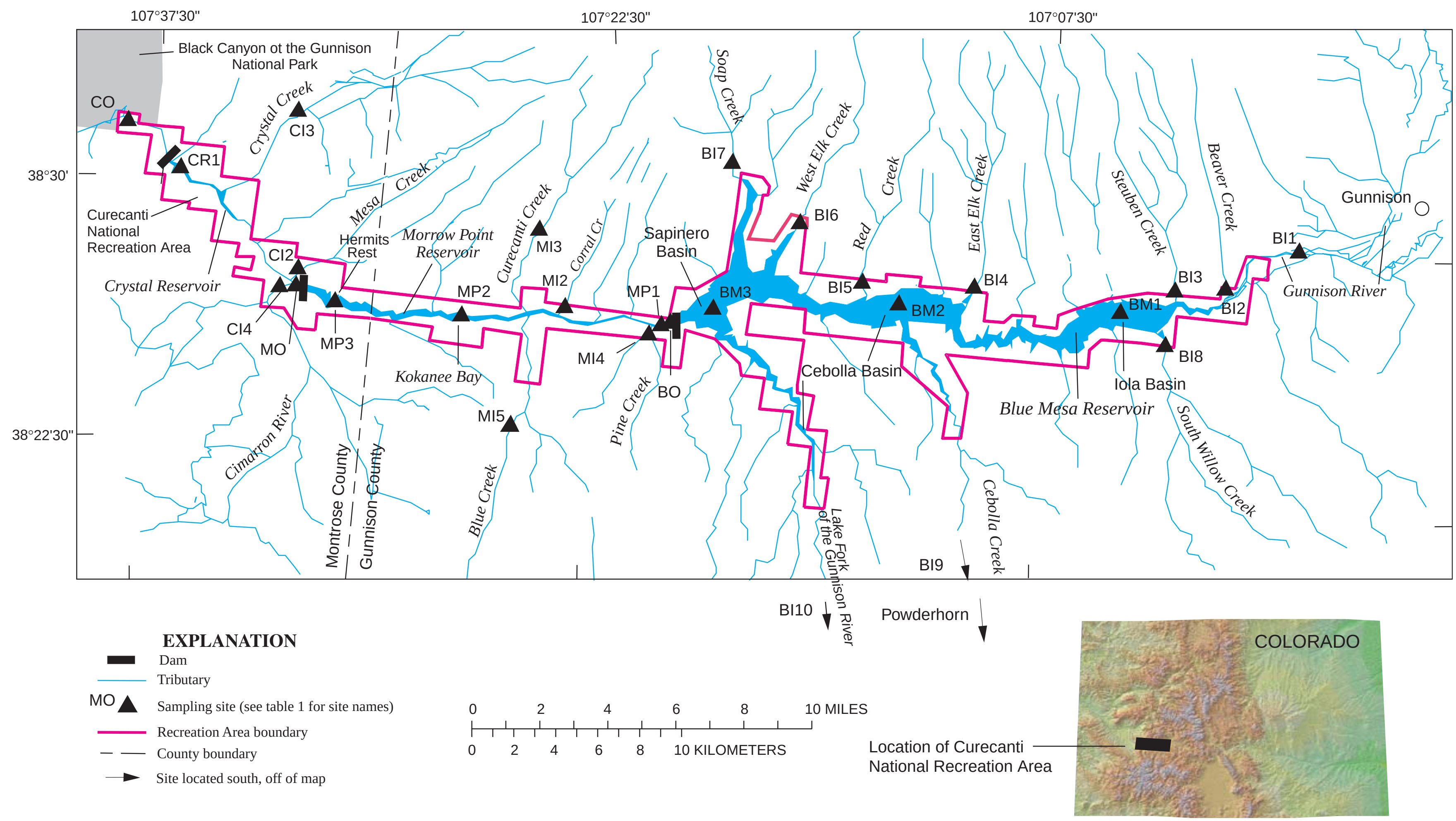

Figure 1. Curecanti National Recreation Area and sampling sites.

To meet these needs, the U.S. Geological Survey (USGS), in cooperation with the National Park Service (NPS), conducted a study in 1999 to investigate the limnological characteristics of Blue Mesa, Morrow Point, and Crystal Reservoirs, including the water quality of stream inflows and reservoir outflows.

Purpose and Scope

The purposes of this report are to (1) describe the limnological characteristics (physical properties and nutrient, phytoplankton, and chlorophyll-*a* concentrations) of Blue Mesa, Morrow Point, and Crystal Reservoirs in Curecanti NRA in 1999; (2) describe 1999 water-quality conditions in stream inflows (physical properties, suspended sediment, and nutrients) and reservoir outflows (physical properties and nutrients) for Blue Mesa, Morrow Point, and Crystal Reservoirs; and (3) compare the nutrient, phytoplankton, chlorophyll-*a*, and(or) trophic status of Blue Mesa Reservoir and its inflows in 1999 to previous levels over the past 25 years with regard to nutrient conditions and nutrient enrichment in the reservoir. The report describes the spatial and temporal distribution of physical properties, nutrients, phytoplankton, chlorophyll-*a*, and trophic status for Blue Mesa, Morrow Point, and Crystal Reservoirs; physical properties, suspended sediment, and nutrients for stream inflows; and physical properties and nutrients for reservoir outflows. Nutrient, phytoplankton, chlorophyll-*a*, and(or) trophic conditions in Blue Mesa Reservoir and two of its inflows are compared to historical data to investigate nutrient conditions and nutrient enrichment with respect to land-use changes in the upper Gunnison River Basin. Included in the analysis of 1999 phytoplankton data for Morrow Point and Crystal Reservoirs is a comparison to 1998 phytoplankton data.

Acknowledgments

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Description of Study Area

Curecanti NRA is located in semiarid west-central Colorado in Gunnison and Montrose Counties. The recreation area begins about 5 mi west of the town of Gunnison and extends about 50 mi to the west (fig. 1). As the Aspinall Unit of the Colorado River Storage Project, Blue Mesa, Morrow Point, and Crystal Reservoirs have a combined storage capacity of approximately 1,083,126 acre-ft of water (Bureau of Reclamation, 1999a). Blue Mesa Reservoir, the most upstream reservoir and the largest body of water in Colorado, has a maximum storage capacity of 940,700 acre-ft and a surface area of 9,180 acres at full pool (elevation of 7,519 ft). Morrow Point Reservoir, downstream from Blue Mesa Reservoir, has a storage capacity of 117,190 acre-ft and a surface area of 817 acres at full pool (elevation of 7,160 ft). Crystal Reservoir, downstream from Morrow Point Reservoir, has a storage capacity of 25,236 acre-ft and a surface area of 301 acres at full pool (elevation of 6,700 ft) (Bureau of Reclamation, 1999a). Each reservoir is used for water storage and the generation of hydroelectric power. Crystal Reservoir also acts to re-regulate fluctuating flows due to power production. The residence time (the average time needed to completely replenish a reservoir's water volume) differs for the three reservoirs and depends on each reservoir's purpose and size. The 1978–99 average residence time for Blue Mesa Reservoir was 202 days; for Morrow Point Reservoir, 36 days; and for Crystal Reservoir, 4.5 days (Bureau of Reclamation, 1975–99). The operation of the Aspinall Unit is controlled by the Bureau of Reclamation, whereas the recreational uses of Curecanti NRA are administered by the NPS.

Blue Mesa Reservoir's 98 miles of shoreline are bordered by rolling hills with dominant vegetation consisting of sagebrush (*Artemisia* sp.) and Gambel oak (*Quercus gambelii*). The surficial geology surrounding Blue Mesa Reservoir consists of sedimentary deposits of Mesozoic age capped with volcanic rocks of Cenozoic age. The Gunnison River (site BI1; fig. 1, table 1) supplies more than one-half of the flow into Blue Mesa Reservoir. A short, free-flowing

Table 1. Sample-collection sites, Curecanti National Recreation Area, April–December 1999

[USGS, U.S. Geological Survey]

Site number (fig. 1)	USGS station number	Site name
		BLUE MESA RESERVOIR—RESERVOIR SITES
BM1	382856107050000	Blue Mesa Reservoir below Highway 149 bridge, near Gunnison (Iola Basin)
BM2	382829107122200	Blue Mesa Reservoir above Highway 50 bridge, near Sapinero (Cebolla Basin)
BM3	382831107172600	Blue Mesa Reservoir above Blue Mesa Powerhouse, near Sapinero (Sapinero Basin)
		BLUE MESA RESERVOIR—INFLOW AND OUTFLOW SITES
BI1	383103106594200	Gunnison River at County Road 32 below Gunnison
BI2	382943107015300	Beaver Creek at Highway 50, near Gunnison
BI3	382937107033500	Steuben Creek at Highway 50, near Gunnison
BI4	382900107101600	East Elk Creek above Highway 50, near Sapinero
BI5	382902107140400	Red Creek above Highway 50, near Sapinero
BI6	383028107162200	West Elk Creek above Blue Mesa Reservoir, near Sapinero
BI7	383137107183600	Soap Creek above Blue Mesa Reservoir, near Sapinero
BI8	382807107033900	South Willow Creek above Highway 149, near Gunnison
BI9	381633107054700	Cebolla Creek at bridge southeast of Powderhorn
BI10	381934107133500	Lake Fork of the Gunnison River below Gateview
BO	382712107200100	Blue Mesa Reservoir discharge at Blue Mesa Powerhouse, near Sapinero
		MORROW POINT RESERVOIR—RESERVOIR SITES
MP1	382711107201200	Morrow Point Reservoir below Blue Mesa Powerhouse, near Sapinero (Above Pine Creek)
MP2	382644107271000	Morrow Point Reservoir below Curecanti Needle, near Sapinero (Kokanee Bay)
MP3	382702107315400	Morrow Point Reservoir above Morrow Point Dam, near Cimarron (Hermits Rest)
		MORROW POINT RESERVOIR—INFLOW AND OUTFLOW SITES
BO	382712107200100	Blue Mesa Reservoir discharge at Blue Mesa Powerhouse, near Sapinero
MI2	382730107232900	Corral Creek at Highway 92, near Sapinero
MI3	09125000	Curecanti Creek near Sapinero
MI4	382702107203900	Pine Creek at Highway 50, near Sapinero
MI5	382418107242600	Blue Creek at Highway 50, near Sapinero
MO	382710107323000	Crystal Reservoir below Morrow Point Dam, near Cimarron (Morrow Point Reservoir discharge)
		CRYSTAL RESERVOIR—RESERVOIR SITE
CR1	383024107371800	Crystal Reservoir near Crystal Dam, near Cimarron
		CRYSTAL RESERVOIR—INFLOW AND OUTFLOW SITES
MO	382710107323000	Crystal Reservoir below Morrow Point Dam, near Cimarron (Morrow Point Reservoir discharge)
CI2	382720107324000	Mesa Creek above Crystal Reservoir, near Cimarron
CI3	383150107333300	Crystal Creek at Highway 92, near Crawford
CI4	09127000	Cimarron River below Squaw Creek, near Cimarron
CO	09128000	Gunnison River below Gunnison Tunnel

segment of the Gunnison River is located in the eastern part of the recreation area upstream from the reservoir. Additional primary inflows to Blue Mesa Reservoir are Lake Fork of the Gunnison River and Cebolla and Soap Creeks (sites BI10, BI9, and BI7, respectively; fig. 1, table 1). Other inflows to Blue Mesa Reservoir are small, and some are ephemeral. The Black Canyon of the Gunnison River begins near Blue Mesa Dam and gives rise to the steep cliffs of Morrow Point and Crystal Reservoirs. Both reservoirs are long and narrow and set deep in the canyon, cutting through igneous and metamorphic rock of Precambrian age. Curecanti Creek and Blue Creek (sites MI3 and MI5, respectively; fig. 1, table 1) are primary stream inflows to Morrow Point Reservoir; the Cimarron River (site CI4; fig. 1, table 1) is the primary stream inflow to the Gunnison River before the beginning of Crystal Reservoir. Other stream inflows to the two downstream reservoirs provide small, often ephemeral, flow. Most of the streamflow in the inflows to all three reservoirs results from snowmelt runoff during spring and localized rainshowers. The reservoirs' watershed is dominated by forests and rangeland (fig. 2). Agricultural land is located adjacent to the Gunnison River and other streams or rivers. The town of Gunnison, population of 5,392 in 1998, is the major urban center in the watershed (Colorado Department of Local Affairs, 1999).

Precipitation and Reservoir Operations

Precipitation in the Gunnison River Basin in 1999 was variable; there were extended periods of dry and wet conditions. Much of the winter season of 1999 (January through March) was characterized by dry conditions resulting from a persistent high pressure system over the Southwestern United States. Conditions began to change during April, with precipitation in the basin 230 percent above average for the month (Paul Davidson, Bureau of Reclamation, written commun., 2000). Precipitation was prevalent throughout the summer months, as heavy thunderstorms from the summer monsoon season began earlier than usual in July and continued into September. Cool temperatures also were prevalent during this time. The fall and early winter seasons of 1999 in the Gunnison River Basin were very dry. Precipitation amounts in October, November, and December were between 20 and 60 percent of average (Paul Davidson, Bureau of Reclamation, written commun., 2000).

The volume of water stored in Blue Mesa Reservoir during 1999 reflected the weather and runoff conditions (fig. 3). Storage in the first 4.5 months of 1999 was relatively constant and ranged between 535,397 and 577,692 acre-ft (Bureau of Reclamation,

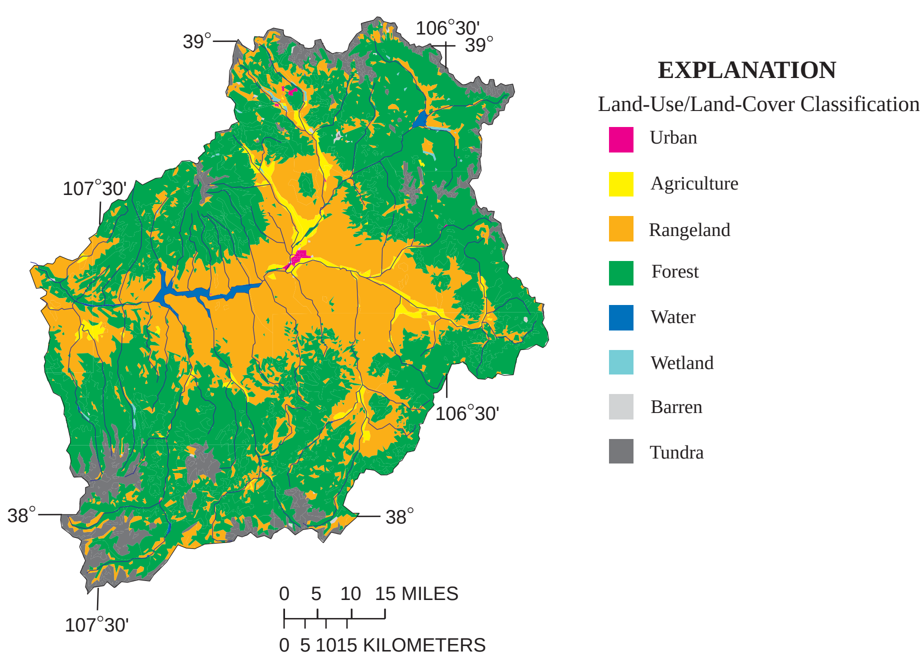

Figure 2. Land-use/land-cover classification, Curecanti National Recreation Area watershed (from Spahr and others, 2000).

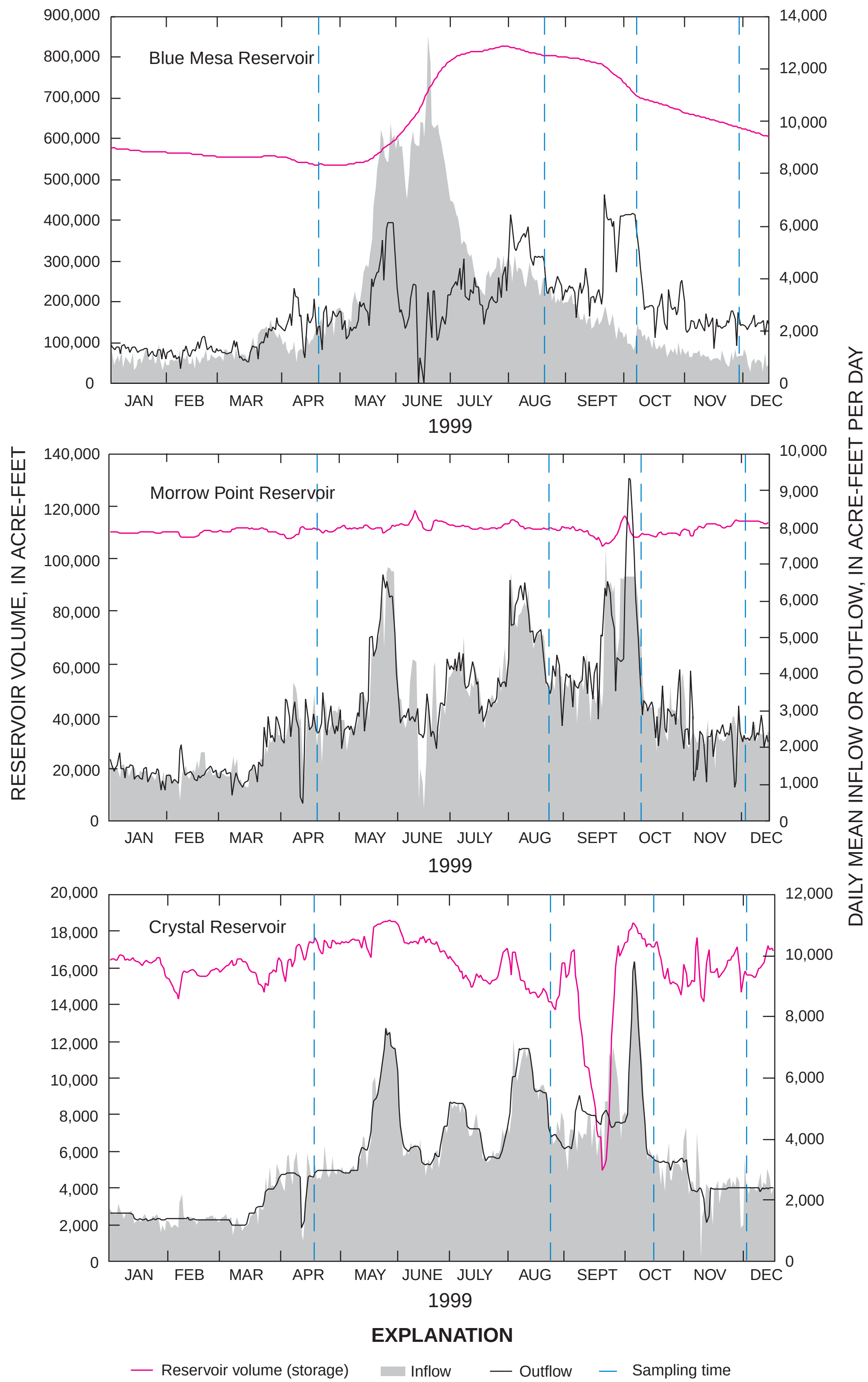

Figure 3. Reservoir volume, inflow, and outflow of water for Blue Mesa, Morrow Point, and Crystal Reservoirs, 1999.

1999b). Storage increased during spring and early summer with greater precipitation and snowmelt conditions and was near full pool from July into September because of monsoon-season rainstorms. Storage amounts decreased during fall and early winter, as water is usually released from Blue Mesa Reservoir at this time of the year to lessen winter icing in the Gunnison River where it enters the reservoir by reducing the lake level. In contrast to Blue Mesa Reservoir, water storage in Morrow Point Reservoir was nearly constant all year, with storage ranging between 104,729 and 118,663 acre-ft (fig. 3) (Bureau of Reclamation, 1999b, 2000). In general, inflows and outflows for Morrow Point Reservoir mirrored each other. Morrow Point Reservoir is primarily used as a power-peaking unit for power generation, and as such, a constant water level or hydraulic head is needed to maximize power production. Storage in Crystal Reservoir in 1999 ranged between about 14,000 and 18,578 acre-ft except for a 2-week period during September (fig. 3). Storage was reduced to a minimum of 4,937 acre-ft on September 17 for maintenance work on the Crystal Dam penstocks (Bureau of Reclamation, 1999b, 2000). As with Morrow Point Reservoir, inflows and outflows for Crystal Reservoir generally mirrored each other, probably indicating a need for power generation and the re-regulation of fluctuating flows. With the increased precipitation in the Gunnison River Basin during April and early May, the amount of water released from each reservoir was increased during May to ensure adequate storage in Blue Mesa Reservoir during snowmelt and the monsoon season. For all three reservoirs, water is drawn through a power-gate slot on the dam face. For Blue Mesa Dam, the power-gate slot is located between the elevations of 7,358 and 7,376 ft; for Morrow Point Dam, between 7,071 and 7,090 ft; and for Crystal Dam, between 6,645 and 6,678 ft (Donald K. Phillips, Bureau of Reclamation, written commun., 2000). The power-gate slot locations result in water being released from deep within each reservoir.

Previous Investigations

Numerous reports pertaining to water quality and aquatic biology in the upper Gunnison River Basin and Curecanti NRA are available. These include investigations on the Gunnison River before and after impoundment; studies on water quality in streams in the upper Gunnison River Basin, including inflows to the recreation area; reports on the trophic status and limnology of Blue Mesa Reservoir; investigations on aquatic biota, including macroinvertebrates, phytoplankton, and fish in the recreation area and inflow streams; and National Park Service reports on water resources of Curecanti NRA.

Knight and Argyle (1962) studied the Gunnison River prior to impoundment. Wiltzius (1965–1967, 1971, 1974, 1976) investigated fisheries and water-quality properties (temperature, dissolved oxygen, pH, specific conductance, turbidity, alkalinity, hardness, and ions) before and after impoundment. Reed (1968) discussed limnological developments after dam completion on the Gunnison River, including blooms of blue-green algae that appeared in the reservoir soon after filling.

Boettcher (1971) studied water quality and supply at six planned or developed sites in the recreation area. Rumberg and others (1978) reported that water in the upper Gunnison River Basin, including Curecanti NRA inflows, was generally of high quality. Aaronson (1982a, 1982b) also investigated water quality in Gunnison River Basin streams. Long and others (1995) analyzed data from 1987 to 1993 for Blue Mesa Reservoir and 11 inflows in the recreation area. It was reported that ambient water quality appeared to vary more spatially than temporally, and few serious effects from natural or anthropogenic factors were detected. As the major inflow to Blue Mesa Reservoir, the Gunnison River had a measurable influence on the reservoir due to its overall volume, including loadings to the reservoir. The Cimarron River had elevated levels of nutrients, bacteria, and dissolved solids as compared to other inflow streams in the recreation area. A retrieval and analysis of surface-water-quality data for Curecanti NRA from six U.S. Environmental Protection Agency (USEPA) databases for the period from 1994 through 1997 indicated generally good water quality in surface waters of the study area with some effects from natural and human activities (National Park Service, 1998a). Spahr and others (2000) provided results from 3 years of water-quality sampling on the Gunnison River upstream and downstream from Curecanti NRA, starting in October 1995. Water quality in the Gunnison River just upstream from Blue Mesa Reservoir was representative of mixed land-use and high-elevation basins. Nitrogen concentrations were commonly highest in winter, and phosphorus concentrations were greatest during or just prior to peak streamflow from snowmelt. Water quality in the Gunnison River just downstream from Crystal Reservoir was relatively dilute with limited variability. No instream water-quality standards of the Colorado Department of Public Health and Environment (Colorado Department of Public Health and Environment, 2001) were exceeded at either of the two Gunnison River sites. Gurdak and others (2002) conducted an analysis of surface- and ground-water-quality data of the Upper Gunnison River watershed for 1969–99. These properties and constituents were measured: in surface and ground water—field properties, major ions, nutrients, and trace elements; in surface water—suspended sediment, chlorophyll-*a*, biochemical oxygen demand, and fecal coliform; and in ground water—radon, pesticides, and volatile organic compounds.

The trophic status and limnology of Blue Mesa Reservoir has been discussed in numerous reports. The U.S. Environmental Protection Agency (1977) reported that Blue Mesa Reservoir was mesotrophic, with nitrogen limitation during late summer and early fall. Blackwell and Boland (1979) used Landsat imagery and principal component analysis techniques to study the trophic status of the reservoir. As part of a large lake and reservoir study in the 1970's, Sapinero Basin (site BM3; fig. 1, table 1) was determined to be oligotrophic in 1975 (Britton and Wentz, 1980). Cudlip and French (1985) also reported that Sapinero Basin was oligotrophic in 1985, as was Cebolla Basin (site BM2; fig. 1, table 1). Iola Basin (site BM1; fig. 1, table 1) was reported to be mesotrophic. Physical, chemical, and biological data for Blue Mesa Reservoir from 1965 through 1985 were summarized by Cudlip and others (1987). Based on data from 1975 and 1983–85, it was suggested that the reservoir reached trophic equilibrium without passing through a period of decreased productivity; the reservoir was mesotrophic in 1985, as in 1975. Hickman (1987) analyzed water-quality data from 1982 through 1985 for trends and determined that no gross pollution or deterioration of water quality occurred in the reservoir over the time period. Effects of changes in reservoir operations on Blue Mesa Reservoir were described in a series of reports by Johnson and Bergstedt (1994) and Johnson and others (1995, 1996, 1997). These reports focused on reservoir limnology (physiochemical characteristics, primary production, and zooplankton dynamics) and fishery investigations. Reservoir thermal ecology, a thermal stratification model, and a growth (bioenergetics) model for kokanee salmon also were discussed in the latter two reports. As a result of the modeling, Johnson and others (1997) concluded that Blue Mesa Reservoir's thermal regime was relatively insensitive to changes in reservoir operations during normal climatic conditions.

Wiltzius (1971, 1974) investigated fish populations in Blue Mesa Reservoir after initial stocking. Wiltzius (1976) also reported on the relation of irrigation diversions and reservoirs to temperature and fish populations. Stanford and Ward (1983, 1985) investigated the effects of dams and river regulation on the Gunnison River. It was reported that seasonal water temperatures downstream from the impoundments were moderated, and dissolved solids and organic carbon were higher downstream. Macroinvertebrates, particularly Plecoptera, Trichoptera, and Ephemeroptera, were studied by Stanford and Ward (1989), Hauer and others (1989), and Ward and Stanford (1990, 1991). In each case, faunal discontinuities resulting from the damming of the Gunnison River were observed. McAda and Kaeding (1990) reported on changes in the Gunnison River from construction of the Aspinall Unit and effects on endangered fish species. Colborn (1981) investigated amounts of trace elements in aquatic insects in Gunnison-area streams. Nehring and Anderson (1983) summarized benthic and fishery studies in the Gunnison River. The National Park Service (1986) gathered data on benthic fauna in Blue Mesa Reservoir's four major inflows and on phytoplankton in the reservoir. The benthic organisms indicated good water quality in the inflow streams. Phytoplankton in Blue Mesa, Morrow Point, and Crystal Reservoirs during 1998 were described by the National Park Service (1998b). Diatoms and blue-green algae were dominant in Blue Mesa Reservoir, while diatoms were dominant in Morrow Point and Crystal Reservoirs. Phytoplankton data for the 1999 study will be compared to phytoplankton data from the 1998 study (National Park Service, 1998b). Studies on catostomid and salmonid fishes in Curecanti NRA were conducted by Middleton (1969) and Wiltzius and Smith (1976), respectively. Analyses of fish tissue for metals were conducted by Kunkle and others (1983). Concentrations were below levels harmful to human beings. Wise (1997) investigated the effects of kokanee salmon predation on the abundance and population dynamics of its preferred prey species, the zooplankton *Daphnia* sp., in 1994 and 1995, and found that kokanee had very little influence on spring *Daphnia* dynamics.

A water-resources scoping report analyzed the water-resource issues facing the recreation area (National Park Service, 1995). Waters in the recreation area were determined to be of high quality. However, upstream land-use activities, including increased urban development, and activities within park boundaries were recognized as potentially affecting water quality. The influence of changes in the operation of the Aspinall Unit on fisheries and reservoir trophic dynamics also was discussed. As a result of the scoping report, the Water Resources Management Plan for Curecanti NRA was developed (Cudlip and others, 1996). This document described the water resources of the recreation area and issues affecting the resources. Eight project statements describing research needs in the recreation area were included in the management plan, including one statement that addressed the lack of information on physical and biological dynamics in Morrow Point and Crystal Reservoirs.

DATA COLLECTION AND ANALYSIS PROCEDURES

The surface-water sampling for this study was designed to investigate the limnology of Blue Mesa, Morrow Point, and Crystal Reservoirs in Curecanti NRA, including nutrient enrichment in Blue Mesa Reservoir, and the water quality of stream inflows and reservoir outflow for each reservoir.

Sample Collection

Water-quality samples were collected four times from April through December 1999 from reservoir, stream inflow, and reservoir outflow sites throughout the recreation area (fig. 1, table 1). Exact dates for sampling depended on the hydrological cycle. For example, the Blue Mesa Reservoir inflow South Willow Creek (site BI8; fig. 1, table 1) was sampled only during spring because of the lack of water the remainder of the year. Water-quality parameters of interest for the respective sites are shown in table 2. Prior to each sample collection, all sampling equipment was cleaned with a nonphosphate detergent and rinsed, in order, with tap water, deionized water, a 5-percent solution of hydrochloric acid, and deionized water (Shelton, 1994). At each sampling site, the equipment also was thoroughly rinsed with native water prior to use. All samples were collected using high-density polyethylene plastic bottles.

Water samples were collected from three sites in Blue Mesa Reservoir, three sites in Morrow Point Reservoir, and one site in Crystal Reservoir (fig. 1, table 1). For ease of reporting, site names for the sample-collection sites in Blue Mesa and Morrow Point Reservoirs hereinafter will be described using the shorter names in parentheses in table 1. The reservoir sampling network for this study overlaps the sampling network operated by Curecanti NRA for their water-quality monitoring program. In 1999, samples were collected from each reservoir site after ice-out during April, at summer stratification, in fall, and in early winter. Onsite measurements included light or Secchi-depth transparency and depth profiles of water temperature, dissolved-oxygen concentration, pH, and specific conductance. The depth profiles were measured using a Hydrolab H20 in-situ water-quality probe. Measurements were taken at 1-m intervals to 20 m and then at 5-m intervals. Water-quality samples for the determination of dissolved and total nutrient constituents were collected at discrete depths by using a vertically suspended, 2.2-L, acrylic Kemmerer sampler.

Table 2. Water-quality parameters of interest

Site type	Water-quality parameters of interest
Reservoir	Physical properties,[1] nutrients,[2] phytoplankton, chlorophyll-*a*
Reservoir inflows	Physical properties,[3] nutrients,[2] suspended sediment
Reservoir outflow	Physical properties,[3] nutrients[2]

[1]Water temperature, dissolved-oxygen concentration, pH, specific conductance, light transparency.

[2]Dissolved ammonia (un-ionized ammonia [NH_3] plus ammonium [NH_4^+]), dissolved nitrite, dissolved nitrate plus nitrite, dissolved and total ammonia plus organic nitrogen, dissolved orthophosphate, dissolved and total phosphorus.

[3]Discharge or streamflow, water temperature, dissolved-oxygen concentration, pH, specific conductance.

For the Morrow Point Reservoir site Above Pine Creek, samples were collected near the surface during each sampling period, with additional samples collected near the bottom of the water column during summer, fall, and early winter. Water at this shallow site was thoroughly mixed at each sampling.

For the other six reservoir sites, two water-quality samples were collected at each site during spring turnover in April, one near the surface and the other from mid-depth of the reservoir. During turnover, the reservoir water was thoroughly mixed, and physical and chemical conditions were similar throughout the water column. Collecting water-quality samples at depth during turnover was done to determine similarities or differences in nutrient concentrations in the water column during turnover. During summer stratification, water-quality samples were collected at the top and bottom of the epilimnion (warm upper stratum) and near the bottom of the water column at the six sites. Additional samples were collected in Blue Mesa Reservoir from the metalimnion (stratum with maximum rate of temperature decrease with depth) during summer stratification. During fall, water-quality samples were collected near the surface and near the bottom of the water column at the six sites. Additional samples were collected from the bottom of the photic (light penetration) zone during early winter when turnover was occurring to determine variability in nutrient concentrations with depth during turnover.

Inflow and outflow samples for each reservoir were collected from 10 stream sites for Blue Mesa Reservoir, 4 for Morrow Point Reservoir, and 3 for Crystal Reservoir (fig. 1, table 1). Samples were collected in spring during high flow and in summer, fall, and early winter during low flows. Except for the spring sampling, sample collection at the stream sites was approximately concurrent with sample collection at the reservoir sites. For the stream sites, field measurements were obtained for streamflow, water temperature, dissolved-oxygen concentration, pH, and specific conductance. Water-quality samples for nutrient and suspended-sediment analysis were collected by equal-width-increment sampling using techniques described by Shelton (1994). At the reservoir-discharge sites downstream from Blue Mesa and Morrow Point Dams, water temperature, dissolved-oxygen concentration, pH, and specific conductance were determined, and water-quality samples were collected as grab samples for nutrient analysis. While these two sites are named as reservoir sites (Blue Mesa Reservoir discharge at Blue Mesa Powerhouse, near Sapinero and Crystal Reservoir below Morrow Point Dam, near Cimarron) in table 1, they are located on free-flowing segments of the Gunnison River just upstream from the reservoirs' beginnings. Samples at the Crystal Reservoir outflow site at Gunnison River below Gunnison Tunnel were collected in the same fashion as the stream sites except that no suspended-sediment samples were collected.

Water-quality samples from all sites were processed onsite using techniques described by Shelton (1994). Samples for the analysis of dissolved nutrient constituents were filtered through a 0.45-μm membrane filter. Dissolved concentrations were determined for ammonia (un-ionized ammonia [NH_3] plus ammonium [NH_4^+]) (as nitrogen), nitrite (as nitrogen), nitrate plus nitrite (as nitrogen), ammonia plus organic nitrogen (as nitrogen), orthophosphate (as phosphorus), and phosphorus (as phosphorus). Samples for the determination of total ammonia plus organic nitrogen (as nitrogen) and total phosphorus (as phosphorus) were unfiltered and preserved with 1 mL of sulfuric acid. All samples were stored on ice prior to delivery to the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colo.

Analysis Methods

Various methods were used to analyze the water-quality data collected in this study. These included laboratory analysis for nutrients and suspended sediment, determination of nutrient ratios and loads, comparison of 1999 water-quality data to water-quality standards, analysis of phytoplankton and chlorophyll-*a*, description of reservoir classification schemes, and trend and correlation analysis.

Laboratory Analysis for Nutrients and Suspended Sediment

The nutrient samples were extracted and analyzed at the NWQL using methods described by Fishman and Friedman (1989), Fishman (1993), and the U.S. Environmental Protection Agency (1993). Concentrations for ammonia, nitrite, nitrate plus nitrite, and orthophosphate were reported in terms of minimum reporting levels (MRLs). The MRL is defined by the NWQL as the smallest measured concentration of a constituent that may be reliably measured using a given analytical method (Timme, 1995). A constituent detected at a concentration less than the MRL or undetected is reported at the MRL with a “<” symbol. Concentrations for ammonia plus organic nitrogen were reported in terms of the long-term method detection level (LT-MDL) and laboratory reporting level (LRL) (Childress and others, 1999). The LT-MDL is the lowest concentration of a constituent that is reported by the NWQL and represents that value at which the chance of a false positive detection is statistically limited to less than or equal to 1 percent. The LRL is calculated at two times the LT-MDL and represents the value at which the rate of false negatives is less than or equal to 1 percent. Concentrations detected between the LT-MDL and LRL are reported as estimated (E) concentrations. Concentrations for dissolved and total phosphorus for samples analyzed before October 1, 1999, were reported using MRLs. Samples analyzed after September 30, 1999, were reported using LT-MDLs and LRLs (Gary Cottrell, U.S. Geological Survey, written commun., 2000). The reporting conventions and reporting values for the different nutrient constituents are given in table 3. For this report, the nitrogen data in this study have been aggregated into total nitrogen and dissolved inorganic nitrogen data to facilitate interpretation and discussion. Concentrations of these two constituents have been calculated from ammonia, nitrite, nitrate plus nitrite, and ammonia plus organic nitrogen concentrations using the procedures described in table 4. Because total nitrogen and dissolved inorganic nitrogen concentrations are computed values, there are no laboratory reporting levels associated with these two constituents. Throughout this report, when total nitrogen and dissolved inorganic nitrogen concentrations are described as being less than laboratory reporting levels, the reporting levels discussed are those for ammonia plus organic nitrogen and nitrate plus nitrite, respectively.

Suspended-sediment samples were analyzed at the USGS Iowa Sediment Laboratory in Iowa City for the determination of concentration, in milligrams per liter. Suspended sediments are important in nutrient analysis, as a large proportion of phosphorus may adhere to the sediment.

Table 3. Reporting conventions and reporting values for nutrient constituents

[MRL, minimum reporting level; LRL, laboratory reporting level; LT-MDL, long-term method detection level; mg/L, milligrams per liter; --, not applicable]

Nutrient	MRL (mg/L)	LRL (mg/L)	LT-MDL (mg/L)
Ammonia, dissolved	0.002	--	--
Nitrite, dissolved	0.001	--	--
Nitrate plus nitrite, dissolved	0.005	--	--
Ammonia plus organic nitrogen, dissolved and total	--	0.1	0.05
Orthophosphate, dissolved	0.001	--	--
Phosphorus, dissolved	[1]0.004	[2]0.006	[3]0.003
Phosphorus, total	[1]0.004	[2]0.008	[3]0.004

[1]Reporting level for samples analyzed before October 1, 1999.
[2]Reporting levels for samples analyzed after September 30, 1999.
[3]Detection levels for samples analyzed after September 30, 1999.

Nutrient Ratios and Loads

Phytoplankton (algae) can assimilate only three of the several different nutrient (nitrogen and phosphorus) compounds available in aquatic ecosystems. The only forms of nitrogen that phytoplankton can use for growth are nitrate, nitrite, and ammonia (inorganic nitrogen), whereas orthophosphate is the only form of phosphorus that phytoplankton can use for growth (Horne and Goldman, 1994). Nitrogen to phosphorus (N:P) ratios can be used to identify which of the two nutrients may be growth limiting for phytoplankton. In general, a N:P ratio greater than 10 (by weight) indicates that phosphorus is the limiting nutrient, whereas a ratio less than 10 indicates that nitrogen is limiting (Horne and Goldman, 1994). A ratio near 10 is in the transition zone between phosphorus and nitrogen limitation. In this study, N:P ratios were computed using nitrate plus nitrite and ammonia concentrations summed as inorganic nitrogen and orthophosphate concentrations. Where both concentrations were less than the reporting limit, the N:P ratio was not determined. In analyzing nutrient data for lakes and reservoirs, N:P ratios should be used with caution because the ratio for limitation may differ depending on the nutrient requirements of the algal genera that are present. Among diatoms, for example, *Tabellaria* sp. and *Fragilaria* sp. reach maximum population densities at orthophosphate concentrations of approximately 0.045 mg/L, while *Scenedesmus* sp. requires a concentration of around 0.5 mg/L (Wetzel, 1983).

Nutrient loads for Gunnison River at County Road 32 and Gunnison River near Gunnison Tunnel were estimated by the rating-curve method (Cohn and others, 1989; Crawford, 1991). Loads were determined for total nitrogen, dissolved inorganic nitrogen,

Table 4. Procedures used to aggregate nitrogen data into total nitrogen and dissolved inorganic nitrogen constituents

[LT-MDL, long-term method detection level; mg/L, milligrams per liter; LRL, laboratory reporting level; MRL, minimum reporting level; ≥, greater than or equal to; <, less than; NO_3+NO_2, nitrate plus nitrite; NO_2, nitrite; ≤, less than or equal to]

Procedures for calculation of total nitrogen and dissolved inorganic nitrogen

TOTAL NITROGEN

	Total ammonia plus organic nitrogen (LT-MDL=0.05 mg/L) (LRL=0.10 mg/L)	+	Nitrate plus nitrite (MRL=0.005 mg/L)	=	Total nitrogen (mg/L)
if	≥0.05	and	≥0.005	then	Sum of total ammonia plus organic nitrogen and nitrate plus nitrite, rounded to one significant figure
if	≥0.05	and	<0.005	then	Total ammonia plus organic nitrogen
if	[1]<0.10	and	<0.005	then	<0.10
if	[1]<0.10	and	<0.10	then	<0.10

DISSOLVED INORGANIC NITROGEN

	Nitrate plus nitrite (NO_3+NO_2) (MRL=0.005 mg/L)	+	Ammonia (MRL=0.002 mg/L)	+	Nitrite (NO_2) (MRL=0.001 mg/L)	=	Dissolved inorganic nitrogen (mg/L)
if	≥0.005	and	≥0.002			then	NO_3+NO_2 +ammonia
if	≥0.005	and	<0.002			then	NO_3+NO_2
if	<0.005	and	≥0.005	and	≥0.001	then	Ammonia +nitrite
if	<0.005	and	≥0.005	and	<0.001	then	Ammonia
if	<0.005	and	<0.002	and	<0.001	then	<0.005
if	<0.005	and	<0.002	and	0.001≤NO_2<0.005	then	<0.005
if	<0.005	and	0.002≤ammonia<0.005	and	0.001≤NO_2<0.005	then	<0.005
if	<0.005	and	0.002≤ammonia<0.005	and	<0.001	then	<0.005

[1]Procedure applies when total ammonia plus organic nitrogen concentration is reported as ≤0.10 only, not when the data are reported as an actual value between the LT-MDL and LRL. Only stream inflow data fall under this rule.

total phosphorus, and dissolved orthophosphate by using 1995–99 (calendar year) data from the Upper Colorado River Basin (UCOL) National Water-Quality Assessment (NAWQA) Program and the USGS computer program load_est2 (Charles Crawford, U.S. Geological Survey, written commun., 2000). Instantaneous sample data and daily streamflow data were used to estimate annual and monthly nutrient loads, reported as mean load in kilograms per day. Because concentrations for some of the nutrients were less than the reporting limit, rating-curve parameters were estimated by the linear attribution method (Chatterjee and McLeash, 1986). Loads could not be estimated for other sites due to lack of data for nutrient concentrations or streamflow, or both. For example, while nutrient data were available for Cebolla Creek, sufficient streamflow data were not available for use in load calculations. Data collected as part of this study were not extensive enough for load determination. Estimates of load calculations using these data would be subject to large uncertainty.

Water-Quality Standards

Water-quality standards for temperature, dissolved oxygen, pH, un-ionized ammonia, nitrite, and nitrate have been established by the State of Colorado for Blue Mesa, Morrow Point, and Crystal Reservoirs and their tributaries (Colorado Department of Public Health and Environment, 2001). The numeric standards are used to determine the allowable concentrations of various parameters in water and are based on a stream-designated use classification for aquatic life, recreation, drinking water, and agriculture. Use classifications for the reservoirs and tributaries are listed in table 5. For the Gunnison River Basin, the temperature standard is a 3°C temperature increase above ambient water temperature, taking into account normal diurnal and seasonal fluctuations. Standards for dissolved oxygen, pH, un-ionized ammonia (chronic), nitrite, and nitrate are listed in table 6 (Colorado Department of Public Health and Environment, 2001). For reservoirs, the dissolved-oxygen standard only applies to the epilimnion and metalimnion strata; the hypolimnion stratum is exempt. Standards for phosphorus have not been established by the State of Colorado. To control eutrophication in lakes and reservoirs, the USEPA has established a recommended concentration limit of 0.05 mg/L for total phosphorus in rivers or streams that drain into lakes and reservoirs (U.S. Environmental Protection Agency, 1986). New nutrient criteria based on ecoregions and type of receiving water are currently being developed on a regional scale (U.S. Environmental Protection Agency, 1998).

Table 5. Stream classification for reservoir and stream inflow sample-collection sites, Curecanti National Recreation Area

[no., number; UGR, Upper Gunnison River; LGR, Lower Gunnison River; data from Colorado Department of Public Health and Environment, 2001]

Stream segment	Basin	Segment no.	Classification
Gunnison River above Blue Mesa Reservoir inlet Blue Mesa, Morrow Point, and Crystal Reservoirs Lake Fork of the Gunnison River	UGR UGR UGR	14 25 29	Aquatic life—Cold water, Class 1[1] Recreation—Class 1a[2] Water supply[3] Agriculture[4]
Beaver, Steuben, East Elk, Red, West Elk, Soap, South Willow, Cebolla, Pine, Blue, Corral, Curecanti, Mesa, and Crystal Creeks; Cimarron River	UGR	26	Aquatic life—Cold water, Class 1[1] Recreation—Class 2[5] Water supply[3] Agriculture[4]
Main stem of Gunnison River from outlet of Crystal Reservoir	LGR	1	Aquatic life—Cold water, Class 1[1] Recreation—Class 1a[2] Water supply[3] Agriculture[4]

[1]Aquatic life—Cold water, Class 1: Waters that support a wide variety of cold-water biota.
[2]Recreation—Class 1a: Waters where primary contact recreational uses have been documented or are presumed to be present.
[3]Water supply: Water suitable for water supply.
[4]Agriculture: Waters suitable for agriculture.
[5]Recreation—Class 2: Waters where primary contact recreation does not exist and cannot be reasonably expected to exist in the future.

Table 6. Water-quality standards for stream segments in the Gunnison River Basin

[Water-quality standards are from Colorado Department of Public Health and Environment, 2001, except for total phosphorus recommendation, which is from the U.S. Environmental Protection Agency, 1986; mg/L, milligrams per liter]

Water-quality parameters	Water-quality standard
Dissolved oxygen	6.0 mg/L
pH	6.5–9.0 standard units
Un-ionized ammonia (chronic)	0.02 mg/L
Nitrite	0.05 mg/L
Nitrate	10 mg/L
Phosphorus, total	[1]0.05 mg/L

[1]Recommended concentration limit in rivers and streams that drain into lakes and reservoirs.

Phytoplankton and Chlorophyll-*a* Analysis

Phytoplankton samples were collected using a 6-inch-diameter conical plankton tow net with a mesh size of 153 µm and a sample vial of 50 mL. The net was lowered vertically into the water to a depth of 15 m and rapidly raised to the surface. The 50-mL vial was removed from the net and the contents poured into a 125-mL sample bottle containing 1 mL of Lugol's solution as a preservative. The sample vial was returned to the tow net, and the net was rinsed to capture any remaining phytoplankton to the sample vial. Again, the 50-mL sample vial was emptied into the sample bottle, making a total sample volume of 100 mL. The samples were stored on ice in the field and refrigerated in the dark in the laboratory until enumeration and identification.

The phytoplankton samples were analyzed by the NPS for taxa presence, abundance, and density. Taxa identification was to the genus level. Phytoplankton density for each sample was determined using a compound microscope with a micrometer disk placed in the eyepiece of the 10X planachromatic objective and a 1-mL Sedgewick-Rafter (S-R) counting cell. One milliliter of the sample was removed from the agitated sample bottle and placed into the S-R counting cell. The total number of phytoplankton was counted across a strip the length of the S-R cell, with three strips counted per sample. For samples that were dense (more than 10 phytoplankton units per field), the number of phytoplankton in 10 or more random fields was counted. Each field constituted 1-µm grid. Phytoplankton were counted in terms of "algal units." A filament of multicellular phytoplankton was counted as one unit, similar to a unicellular phytoplankton. Results for phytoplankton counts are discussed in terms of algal units per liter (algal units/L).

Chlorophyll-*a*, the primary photosynthetic pigment in algae, is used during photosynthesis to convert light energy into the creation of new organic matter (Wetzel, 1983). As such, chlorophyll-*a* concentrations can be used as indicators of primary productivity and trophic status. Chlorophyll-*a* concentrations were determined for the 0–5-m depth interval for each reservoir site and sampling event. Chlorophyll-*a* samples were collected using a 5-m PVC pipe. The pipe was inserted vertically into the water up to the 5-m mark, and a cord was pulled to stopper the pipe end. The collected water was poured in a rinsed 5-gal bucket, and a 1-L composited subsample was collected and stored in the dark on ice in the field. The chlorophyll-*a* samples were analyzed by standard method 10200H.2, spectrophotometric determination of chlorophyll (American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1999).

Reservoir Classification Schemes

An index developed by Likens (1975) uses chlorophyll-*a* concentrations of phytoplankton to determine the trophic level of a lake or reservoir. According to Likens (1975), chlorophyll-*a* concentrations of 0–3 mg/m^3 indicate oligotrophic conditions, 2–15 mg/m^3 constitute mesotrophic conditions, and 10–500 mg/m^3 are associated with eutrophic conditions. Oligotrophic lakes or reservoirs have very low nitrogen and phosphorus concentrations and limited productivity. Mesotrophic reservoirs have moderate concentrations of nitrogen and phosphorus and significant productivity, and eutrophic reservoirs are characterized by high levels of nutrients and organic matter and are highly productive for plant growth (North American Lake Management Society, 2000).

Another system to classify lakes and reservoirs was developed by Carlson (1977). A numeric trophic-state index (TSI) is calculated from Secchi-disc transparency, chlorophyll-*a* concentrations, or total phosphorus concentrations, using a distinct formula for each parameter. The TSI is on a scale of 0 to 100, and each major division (10, 20, 30, and so forth) represents a doubling of surface algal biomass (Carlson, 1977). The TSI numbers generated from the formulas are only an index of the trophic state of a lake or reservoir, not a definition of the trophic state. An index can be used in lake or reservoir management. For example, the biological conditions of a water body can be estimated using different scenarios of total phosphorus concentrations. For the classification system, Carlson (1977) suggests that priority be given to biological parameters, especially the chlorophyll-*a* index in summer, and possibly the phosphorus index for times of the year when phosphorus is not the limiting nutrient. In developing the chlorophyll-*a* index, Carlson (1977) used a fluorometric method to determine chlorophyll-*a* concentrations. Chlorophyll-*a* concentrations derived from the fluorometric method are higher than concentrations derived from spectrophotometric methods, such as were used in this study. The index values for chlorophyll-*a* in this study are, thus, lower than they would be if the fluorometric method had been used. Chlorophyll-*a* indices for Blue Mesa, Morrow Point, and Crystal Reservoirs will only be used to compare among the three reservoirs. These indices should not be used to compare with other reservoirs or in cases where the chlorophyll-*a* analysis method has changed over time. Historical chlorophyll-*a* values cited in this report for Blue Mesa Reservoir also were determined from spectrophotometric methods.

Trend and Correlation Analysis

Water-chemistry, nutrient, and(or) chlorophyll-*a* data for Iola and Sapinero Basins in Blue Mesa Reservoir, Gunnison River at County Road 32, and Lake Fork of the Gunnison River were tested for temporal trends to determine if water quality in the reservoir and the inflows has changed over time; these were the only sites in this study with extensive historical nutrient data and streamflow measurements (inflow streams only) that could be used in trends testing. The amount of inflow to Blue Mesa Reservoir also was tested for temporal trends. For each site, table 7 lists the constituents used in the seasonal Kendall test for trends, time period of test, source of data, and number of seasons used in test.

In the seasonal Kendall test, variations in constituent data due to seasonality were accounted for by comparing data for the same periods or "seasons" (Helsel and Hirsch, 1992). For example, dissolved-oxygen concentrations for May of one year were compared only with May dissolved-oxygen concentrations of other years. The seasonal Kendall test for trends determines whether the seasonal Kendall tau value, which measures the strength of the monotonic relationship between time and some other variable, is significantly different from zero at a *p*-value (significance level) of 0.05. As tau deviates more from zero, with zero meaning no trend, the greater is the likelihood of a trend. For those sites with trends testing on May through September data only that had more than one data value for the month, the median value for the month was used in the trend test. Because data for Iola Basin was available for a period longer than 10 years, the *p*-value was corrected for serial correlation. Nutrient concentrations for Gunnison River at County Road 32 and Lake Fork of the Gunnison River were adjusted for streamflow prior to trend testing, as were specific-conductance values for the Gunnison River at County Road 32. Trend testing for this latter site was divided into two time periods based on source of data: 1995–99 for nutrient and streamflow data from the UCOL study and from this study, and 1987–94 for nutrient data from the NPS (site is named Gunnison River at Riverway by NPS). Streamflow data for the 1987–94 time period were from USGS gaging stations Gunnison River near Gunnison (station number 09114500) and Tomichi Creek at Gunnison (09119000) (http://water.usgs.gov/co/nwis accessed December 1, 2001). Daily streamflow data were not available for Gunnison River at County Road 32 for 1987–94, but streamflow at this site is the combined flow of the Gunnison River near Gunnison and Tomichi Creek. Nutrient data for Lake Fork of the Gunnison River were for 1995–99. Streamflow data for this site were from USGS gaging station Lake Fork at Gateview (09124500) (http://water.usgs.gov/co/nwis accessed December 1, 2001). Trend-analysis results are presented in the section titled "Retrospective of Nutrient Conditions in Blue Mesa Reservoir."

Care must be used in interpreting trend results. A trend that may be statistically significant may not be important environmentally in cases when the trend is small or the concentrations are very low. Also, trend results depend on the period of record and may differ for different time periods.

Correlation analyses using the rank Kendall correlation coefficient (Kendall's tau) were undertaken to test for relationships between reservoir

Table 7. Information used in seasonal Kendall test for temporal trends

[Periods are in water years (WY), except for Blue Mesa Reservoir inflow, which is in calendar years; site number refers to table 1 and figure 1; BOR, Bureau of Reclamation; NPS, National Park Service; CURE, U.S. Geological Survey and National Park Service data collection in 1999; UCOL, Upper Colorado River Basin National Water-Quality Assessment Program; NWIS, USGS National Water Information System; Gunnison River at Riverway is NPS name for Gunnison River at County Road 32]

Constituent or property	Time period (in WY)	Source of data	Number of seasons
	BLUE MESA RESERVOIR		
Inflow amount	1984–99	BOR	4
	BLUE MESA RESERVOIR AT IOLA (SITE BM1) AND SAPINERO (SITE BM3) BASINS		
pH, specific conductance, Secchi depth, total ammonia plus organic nitrogen, total phosphorus, chlorophyll-*a*	Iola Basin: May through September 1984–99 (pH, Secchi depth, specific conductance, chlorophyll-*a*), May through September 1987–99 (total ammonia plus organic nitrogen, total phosphorus) Sapinero Basin: May through September 1992–99	NPS, CURE	5
	GUNNISON RIVER AT COUNTY ROAD 32 BELOW GUNNISON (SITE BI1)		
Specific conductance, total ammonia plus organic nitrogen, dissolved inorganic nitrogen, total phosphorus, dissolved orthophosphate	1995–99	UCOL, CURE	4
Specific conductance, total ammonia plus organic nitrogen, total phosphorus	May through September 1987–94	NPS—water quality (Gunnison River at Riverway) NWIS—streamflow	5
	LAKE FORK OF THE GUNNISON RIVER BELOW GATEVIEW (SITE BI10)		
Total ammonia plus organic nitrogen, total phosphorus	1995–99	NPS—water quality NWIS—streamflow	1

parameters (including pH and chlorophyll-*a* concentrations, and chlorophyll-*a* concentrations and phytoplankton density) and between total phosphorus and chlorophyll-*a* concentrations in an inflow and reservoir, respectively. As such, the correlation analyses were used as an additional tool for understanding reservoir dynamics. Values of pH in a reservoir, for example, vary because of chemical and biological factors, especially carbon dioxide in the water column. Correlation analyses using pH and chlorophyll-*a* concentrations (as a proxy for carbon dioxide use) were done to see if changes in pH were related to chlorophyll-*a* concentrations and, hence, carbon dioxide use. Two parameters were correlated when the rank Kendall correlation coefficient was significantly different from zero at a *p*-value of 0.05. A value of zero indicated that there was no relationship between the two parameters. When two or more values of a parameter were available in a month, the median value was used in the correlation analysis. Flow-adjusted concentrations were used in correlation analyses involving specific conductance or nutrients in stream inflows.

QUALITY-CONTROL METHODS AND ANALYSIS

Quality-control (QC) samples were used to assess the variability and bias of water-quality data that may be introduced by sample collection, processing, storage, and analysis. Replicate and field-blank samples were collected and processed as QC samples using the same equipment and procedures as the regular or environmental samples in order to evaluate the variability and bias of the water-quality data. Replicate and field-blank samples were collected for nutrient analysis. Replicate samples only were collected for suspended-sediment and phytoplankton analyses. Additional information on QC procedures and samples is given in Shelton (1994).

Replicate samples were used to test for variability, which is the degree of random error in independent measurements of the same quantity (Spahr and Boulger, 1997). Replicate samples were collected in sequence at a site to yield samples of nearly identical composition. By comparing the analytical results of the first sample (environmental sample) with the second sample (quality-control sample), the replicates provide information on the precision of the concentration values and the consistency in identifying the parameter of interest. Replicate samples were analyzed by determining the absolute difference between the environmental sample and the quality-control sample.

For the nutrient sampling, 63 nutrient replicate pairs were studied: 8 different pairs for all nutrients except nitrate plus nitrite (7 replicate pairs), with a replicate pair consisting of the environmental sample and the subsequent quality-control sample. Four replicate pairs each were collected at reservoir and inflow sites. The absolute difference was determined for each nutrient replicate pair and is listed in table 8 by site type. Forty-three percent (27 of 63) of the nutrient replicate pairs had no absolute difference; the environmental sample and the quality-control sample had the same concentration. For the remaining replicate pairs, the absolute differences were low. Excluding the ammonia plus organic nitrogen constituents with higher reporting levels, only one nitrate plus nitrite replicate pair (reservoir site) and one total phosphorus replicate pair (inflow site) had absolute differences greater than 0.005 mg/L. Concentrations for both replicate pairs were elevated, as compared to most other replicate pairs. The two absolute differences above 0.005 mg/L were not unexpected given the random nature of independent measurements and the elevated concentrations. Relative percent differences for these two replicate pairs were small, 10 and 5 percent, respectively. The median absolute differences for all nutrients were of the same order of magnitude as the reporting level; the median variabilities were very low (table 9). Because inflow sites in this study were sampled using procedures of the NAWQA Program, sampling variability and 95-percent confidence intervals could be calculated for the inflow sites using NAWQA quality-control data (Mueller, 1998). Table 10 lists the procedures and results for calculating sampling variability and 95-percent confidence intervals for individual measurements and mean concentrations. An example interpretation is as follows: The critical value for total phosphorus is 0.05 mg/L, the recommended concentration limit in rivers or streams that drain into lakes and reservoirs for control of eutrophication (U.S. Environmental Protection Agency, 1986). At this concentration, the estimated sampling variability is 0.006 mg/L, and the 95-percent confidence interval range is 0.038–0.062 mg/L (table 10). As such, the

Table 8. Concentrations and absolute differences of nutrients in replicate samples

[mg/L, milligrams per liter; <, concentration less than the laboratory reporting level; E, estimated]

Concentration in replicates (mg/L)	Absolute difference	Concentration in replicates (mg/L)	Absolute difference	Concentration in replicates (mg/L)	Absolute difference	Concentration in replicates (mg/L)	Absolute difference
RESERVOIR SITES							
Ammonia, dissolved							
0.005 0.004	0.001	0.002 0.007	0.005	<0.002 <0.002	0.000	<0.002 <0.002	0.000
Nitrite, dissolved							
0.001 <0.001	[1]0.001	<0.001 0.001	[1]0.001	0.001 0.001	0.000	<0.001 <0.001	0.000
Nitrate plus nitrite, dissolved							
[2]0.07 [2]0.08	[2]0.01	0.073 0.066	0.007	<0.005 <0.005	0.000	0.031 0.030	0.001
Ammonia plus organic nitrogen, dissolved							
0.1 0.1	0.0	0.2 0.2	0.0	0.1 0.2	0.1	0.2 0.2	0.0
Ammonia plus organic nitrogen, total							
0.1 0.2	0.1	0.3 0.2	0.1	0.1 0.2	0.1	0.1 0.1	0.0
Orthophosphate, dissolved							
0.004 0.003	0.001	0.028 0.028	0.000	0.006 0.006	0.000	0.007 0.008	0.001
Phosphorus, dissolved							
<0.004 <0.004	0.000	0.031 0.033	0.002	0.008 0.009	0.001	0.013 0.013	0.000
Phosphorus, total							
0.011 0.011	0.000	0.041 0.040	0.001	0.011 0.012	0.001	0.020 0.019	0.001
INFLOW SITES							
Ammonia, dissolved							
0.010 0.010	0.000	0.010 0.013	0.003	<0.002 0.005	[1]0.005	0.005 <0.002	[1]0.005
Nitrite, dissolved							
0.002 0.002	0.000	0.001 0.002	0.001	<0.001 0.001	[1]0.001	0.001 0.001	0.000
Nitrate plus nitrite, dissolved							
0.030 0.028	0.002	<0.005 <0.005	0.000	<0.005 <0.005	0.000	0.140 0.140	0.000
Ammonia plus organic nitrogen, dissolved							
0.3 0.3	0.0	0.2 0.2	0.0	0.1 0.1	0.0	E 0.05 E 0.07	0.02
Ammonia plus organic nitrogen, total							
0.6 0.5	0.1	0.3 0.3	0.0	0.1 0.1	0.0	0.1 0.1	0.0
Orthophosphate, dissolved							
0.036 0.036	0.000	0.061 0.062	0.001	0.033 0.037	0.004	0.035 0.036	0.001
Phosphorus, dissolved							
0.043 0.044	0.001	0.068 0.070	0.002	0.044 0.043	0.001	0.047 0.049	0.002
Phosphorus, total							
0.169 0.178	0.009	0.095 0.096	0.001	0.058 0.057	0.001	0.069 0.072	0.003

[1]Zero was substituted for the "less than" value to yield the maximum difference that could have occurred.

[2]Environmental and quality-control samples were analyzed to two significant figures and not three significant figures, as for low-level nutrients. Thus, this replicate pair is not included in the discussion of replicate results.

Table 9. Range of absolute differences in replicate samples for individual nutrients

[mg/L, milligrams per liter]

Nutrient	Minimum absolute difference (mg/L)	Median absolute difference (mg/L)	Maximum absolute difference (mg/L)	Reporting level (mg/L)
RESERVOIR SITES				
Ammonia, dissolved	0.000	[1]0.001	0.005	0.002
Nitrite, dissolved	0.000	[1]0.001	0.001	0.001
Nitrate plus nitrite, dissolved	0.000	0.001	0.007	0.005
Ammonia plus organic nitrogen, dissolved	0.0	0.0	0.1	0.1
Ammonia plus organic nitrogen, total	0.0	0.1	0.1	0.1
Orthophosphate, dissolved	0.000	[1]0.001	0.001	0.001
Phosphorus, dissolved	0.000	[1]0.001	0.002	[2]0.004 [3]0.006
Phosphorus, total	0.000	0.001	0.001	[2]0.004 [3]0.008
INFLOW SITES				
Ammonia, dissolved	0.000	0.004	0.005	0.002
Nitrite, dissolved	0.000	[1]0.001	0.001	0.001
Nitrate plus nitrite, dissolved	0.000	0.000	0.002	0.005
Ammonia plus organic nitrogen, dissolved	0.0	0.0	0.02	0.1
Ammonia plus organic nitrogen, total	0.0	0.0	0.1	0.1
Orthophosphate, dissolved	0.000	0.001	0.004	0.001
Phosphorus, dissolved	0.001	[1]0.002	0.002	[2]0.004 [3]0.006
Phosphorus, total	0.001	0.002	0.009	[2]0.004 [3]0.008

[1]Rounded concentration.
[2]Reporting level for samples analyzed before October 1, 1999.
[3]Reporting level for samples analyzed after September 30, 1999.

potential error in the 0.05-mg/L measurement due to sampling variability is ±0.012 mg/L or a relative error of ±24 percent. The higher sampling variabilities for ammonia plus organic nitrogen and total phosphorus being greater than dissolved phosphorus, which is greater than orthophosphate, may be due to differences in analytical methods and difficulties in obtaining representative laboratory subsamples from the unfiltered (total) field samples (Mueller, 1998).

These procedures for estimating sampling variability and 95-percent confidence intervals also could be done for other individual nutrient measurements or for comparing mean nutrient concentrations among inflow sites. For the Curecanti NRA reservoir sites, a large quality-control data set similar to the NAWQA stream quality-control data was not available, and sampling variability and 95-percent confidence intervals for reservoir nutrient concentrations could not be calculated.

Field-blank samples were used to test for bias, defined as the systematic error inherent in sampling and analytical methods (Spahr and Boulger, 1997). Blank samples were inorganic-free water that contained no detectable concentrations of the nutrients of interest. The blank water was processed through the sampling equipment and handled and analyzed in the same manner as the environmental samples. Because nutrients in this study were analyzed to low concentrations in the laboratory, field blanks were useful in determining possible contamination of a sample from collection, processing, cleaning, storage, and analysis procedures.

Table 10. Estimated sampling variability and confidence intervals around measured nutrient concentrations at selected maximum or critical values and mean concentrations for interpretation of environmental data for Curecanti National Recreation Area stream inflow sites

[Table modified from Mueller (1998); equations from Mueller (1998); mg/L, milligrams per liter]

Constituent	Maximum or critical value (mg/L)	Mean concentration (mg/L)	Estimated sampling variability[1] (mg/L)	Estimated parameter values for determining sampling variability[2]			95-percent confidence interval (mg/L)	
				B1	B2	B3	For the maximum or critical value[3]	For the mean concentration[4]
Ammonia, dissolved	[5]0.031	0.005	0.004	0.003889	1.302	3.151	0.023–0.039	0.004–0.006
Nitrate plus nitrite, dissolved	[5]0.17	0.025	0.009	0.008629	2.462	3.020	0.15–0.19	0.023–0.027
Ammonia plus organic nitrogen, dissolved	[5]0.5	0.145	0.034	0.03346	0.9141	3.769	0.434–0.566	0.138–0.152
Ammonia plus organic nitrogen, total	[5]0.6	0.189	0.060, 0.011	0.007993	1.633	0.7950	0.483–0.717	0.187–0.191
Orthophosphate, dissolved	[6]0.05	0.036	0.003, 0.002	0.002076	4.503	0.1549	0.045–0.055	0.0355–0.0365
Phosphorus, dissolved	[7]0.05	0.042	0.005	0.004816	2.949	0.6719	0.041–0.059	0.041–0.043
Phosphorus, total	[6]0.05	0.069	0.006, 0.007	0.005855	3.133	0.2846	0.038–0.062	0.068–0.070

[1]$ESV=B1+e^{(-B2-B3/C)}$. C is maximum or critical value or mean concentration; e is the base of natural logarithms. Results are rounded. When two numbers are listed for a nutrient, the first number is sampling variability for maximum or critical value, and the second number is sampling variability for mean concentration.

[2]From Mueller (1998).

[3]CI=C±1.96(ESV).

[4]CI=C±1.96(ESV/SQRT(77)). (There were a total of 77 inflow measurements.)

[5]Maximum detected concentration. These values are used because detected concentrations were much lower than water-quality standards (un-ionized ammonia and nitrate plus nitrite) or standards have not been established (ammonia plus organic nitrogen). Values are used here for comparison to other nutrients.

[6]Critical value recommended to avoid eutrophication (U.S. Environmental Protection Agency, 1986).

[7]No critical value has been identified. Value used here is for comparison to other nutrients.

Nine field-blank samples were collected in this study. Analytical results are listed in table 11 in order of date of collection for reservoir sites, followed by inflow sites. The shaded cell represents the one ammonia concentration that was greater than twice the laboratory reporting level. Concentrations of dissolved and total ammonia plus organic nitrogen and dissolved and total phosphorus were not detected in the nine field-blank samples. Most sites sampled just prior to the blank processing had these nutrients detected above the respective reporting levels. Therefore, the potential for contamination of samples with dissolved and total ammonia plus organic nitrogen and dissolved and total phosphorus during sample collection, processing, cleaning, shipping, and analysis procedures was minimal. Ammonia, nitrite, nitrate plus nitrite, and orthophosphate were each detected in low concentrations in some field-blank samples for reservoir and inflow sites (table 11). Blank water samples can become contaminated with ammonia when exposed to the atmosphere, especially when analyzed to low concentrations as was done in this study. For some of the blank samples with detections of nitrite, the original container of blank water contained nitrite at a concentration of 0.001 mg/L, the level detected in the field-blank samples. All four of the nutrients detected in the field-blank samples were detected at very low concentrations, up to a few thousandths of a milligram of the respective reporting level. These concentrations were within the expected instrument or method variance, and no blank corrections were required to be made to the environmental data (Gary Cottrell, U.S. Geological Survey, oral commun., 2000).

Four replicate pairs were studied for suspended-sediment analysis. Concentrations for the environmental and quality-control samples, respectively, were 133, 155 mg/L; 6, 6 mg/L; 3, 2 mg/L, and 9, 9 mg/L. As such, the absolute difference was low or nonexistent at low concentrations and greater at higher concentrations. Most (75 percent) suspended-sediment concentrations for the tributaries to the three reservoirs were equal to or below 10 mg/L. Based on the replicate data, no adjustments to the suspended-sediment concentrations were needed.

For the phytoplankton data, two replicate pairs were available for analysis. For some phytoplankton genera, higher counts of algal units per liter displayed less precision between environmental and quality-control samples, respectively: *Asterionella* sp., 433, 158 algal units/L; *Tabellaria* sp., 108, 53 algal units/L; and *Melosira* sp., 252, 129 algal units/L. For replicate pairs with low (less than 5) counts of algal units per liter, there was less consistency in the presence or

Table 11. Concentrations of nutrients in blank samples

[Shaded cell represents concentration greater than twice the laboratory reporting level; mg/L, milligrams per liter; <, concentration less than the laboratory reporting level; E, estimated]

Ammonia, dissolved (mg/L)	Nitrite, dissolved (mg/L)	Nitrate plus nitrite, dissolved (mg/L)	Ammonia plus organic nitrogen, dissolved (mg/L)	Ammonia plus organic nitrogen, total (mg/L)	Orthophosphate, dissolved (mg/L)	Phosphorus, dissolved (mg/L)	Phosphorus, total (mg/L)
			RESERVOIR SITES				
<0.002	0.001	[1]<0.05	<0.1	<0.1	0.001	<0.004	<0.004
0.004	0.001	<0.005	<0.1	E 0.07	<0.001	<0.004	<0.004
0.004	0.001	<0.005	<0.1	<0.1	0.002	<0.006	<0.008
<0.002	<0.001	0.008	<0.1	<0.1	<0.001	<0.006	<0.008
0.002	<0.001	<0.005	<0.1	<0.1	<0.001	<0.006	<0.008
			INFLOW SITES				
0.005	<0.001	0.008	<0.1	<0.1	0.001	<0.004	<0.004
<0.002	0.001	<0.005	<0.1	<0.1	0.001	<0.004	<0.004
0.003	0.001	<0.005	<0.1	<0.1	0.002	<0.006	<0.008
0.002	<0.001	0.008	<0.1	<0.1	<0.001	<0.006	<0.008

[1]Sample was analyzed to two significant figures and not three significant figures, as for low-level nutrients.

absence of phytoplankton genera. Phytoplankton that were present in only one sample of these replicate pairs included *Dinobryon* sp., *Stephanodiscus* sp., *Navicula* sp., *Ceratium* sp., *Synedra* sp., *Chlamydomonas* sp., *Pandorina* sp., and *Staurastrom* sp. Phytoplankton typically have a horizontal and vertical spatial distribution that is uneven. Uneven distribution can be caused by such factors as rapid reproduction, unequal grazing by zooplankton, and algal movement (Horne and Goldman, 1994). The uneven nature of phytoplankton distribution should be considered when interpreting the phytoplankton data presented in this report.

LIMNOLOGY OF BLUE MESA RESERVOIR

Reservoir data discussed in this section are listed in tables 22–28 of the “Supplemental Data” section at the back of this report. Please note that profile measurements in Sapinero Basin did not extend to the bottom of the water column in August and October due to inadequate cable length on the Hydrolab water-quality probe.

Physical Properties

Water temperature in Blue Mesa Reservoir ranged from 19.3°C at 1 m below the water surface to 4.2°C at depth (fig. 4*A*, tables 22–24). Temperatures throughout the water column were coldest during April and warmest during August. Water temperatures at the 1-m depth reflected a downstream gradient pattern, as Iola Basin was warmer than Cebolla and Sapinero Basins during spring and summer and cooler during early winter. Isothermal or mixing conditions were present in each basin during spring and early winter and also in Iola Basin during fall. Each basin was thermally stratified during summer, with stratification continuing in Cebolla and Sapinero Basins during fall (fig. 4*A*). Three distinct temperature zones were present in Blue Mesa Reservoir: the epilimnion (upper stratum of uniformly warm water), metalimnion (thermocline or stratum with the greatest rate of temperature decrease with depth), and the hypolimnion (deep stratum of uniformly cold water). In Cebolla and Sapinero Basins, the epilimnion was deeper during fall than summer because of cooling and some circulation.

Dissolved-oxygen concentrations in each basin were highest (9.2–10.0 mg/L) during April when the reservoir was coolest, reflecting the inverse relationship between water temperature and dissolved-oxygen concentrations (fig. 4*A*, tables 22–24). The minimum concentrations of 1.5 and 3.6 mg/L occurred at depth in Cebolla and Sapinero Basins, respectively, during October and November. Although dissolved-oxygen concentrations were very low, anoxic conditions (dissolved-oxygen concentrations around 0.0 mg/L) were not present. Uniform dissolved-oxygen concentrations with depth tended to occur with isothermal conditions, whereas concentrations generally decreased with depth or were more variable during stratification. During summer and fall, dissolved-oxygen concentrations in Cebolla and Sapinero Basins were at a minimum in the metalimnion. Dissolved-oxygen concentrations in the epilimnion of each basin were above the Colorado water-quality standard of 6.0 mg/L (table 6), except for one instance in Sapinero Basin during fall. Concentrations in the metalimnion primarily were below the standard, especially in Cebolla and Sapinero Basins during fall with concentrations near 4.0 mg/L or lower (fig. 4*A*). Although below the standard, these values are not uncommon for deeper strata in lakes and reservoirs.

In Blue Mesa Reservoir, pH ranged from 7.0 to 8.4 standard units (fig. 4*B*, tables 22–24). Seasonally, pH in near-surface (0–10 m) waters of the reservoir was lowest during early winter and higher at other times of the year. The water-column distribution of pH reflected thermally stratified or unstratified conditions in the reservoir. During isothermal conditions, pH values were nearly uniform throughout much of the water column. With stratification, pH was fairly uniform in the epilimnion and hypolimnion of each basin and varied in the metalimnion (fig. 4*B*). All pH values were well within the Colorado water-quality standard (table 6). For each site in Blue Mesa Reservoir, there was no correlation between pH values and chlorophyll-*a* concentrations, as measured by the rank Kendall correlation coefficient at a significance level of $p \leq 0.05$.

Specific conductance in Blue Mesa Reservoir varied from 137 to 228 µS/cm (fig. 4*B*, tables 22–24). These values would indicate dissolved-solids concentrations of 82–137 mg/L, using a conversion factor of 0.6 for the moderately mineralized water (Hem, 1985). At the 1-m depth, specific conductance decreased in a downstream direction, with the highest values in Iola Basin and the lowest in Sapinero Basin. For each basin, specific conductance was at a maximum during spring. Specific-conductance values generally were consistent throughout the water column in each basin when isothermal conditions were present. With stratification,

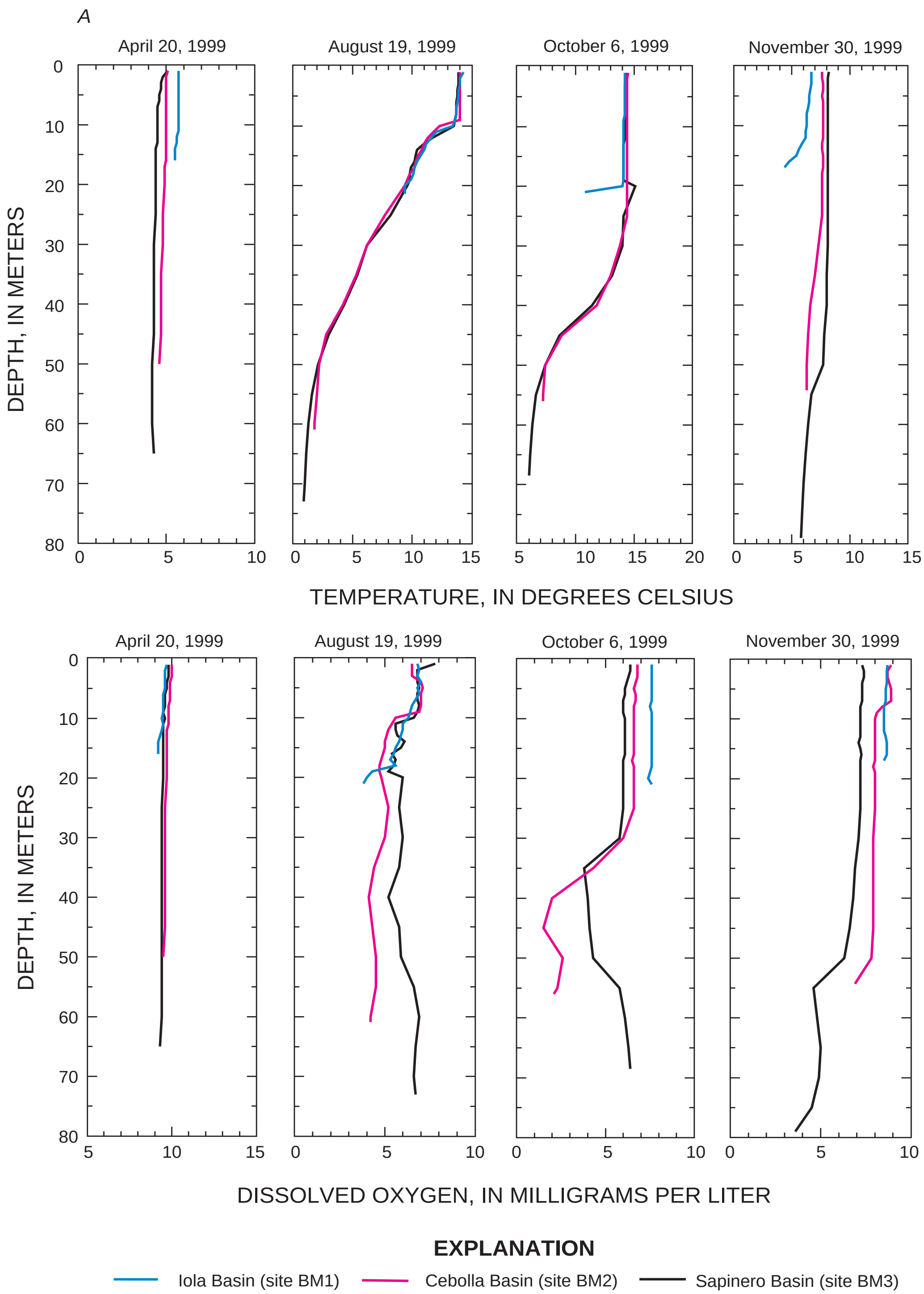

Figure 4. Depth profiles of (*A*) water temperature and dissolved oxygen, and (*B*) pH and specific conductance, Blue Mesa Reservoir, April–November 1999.

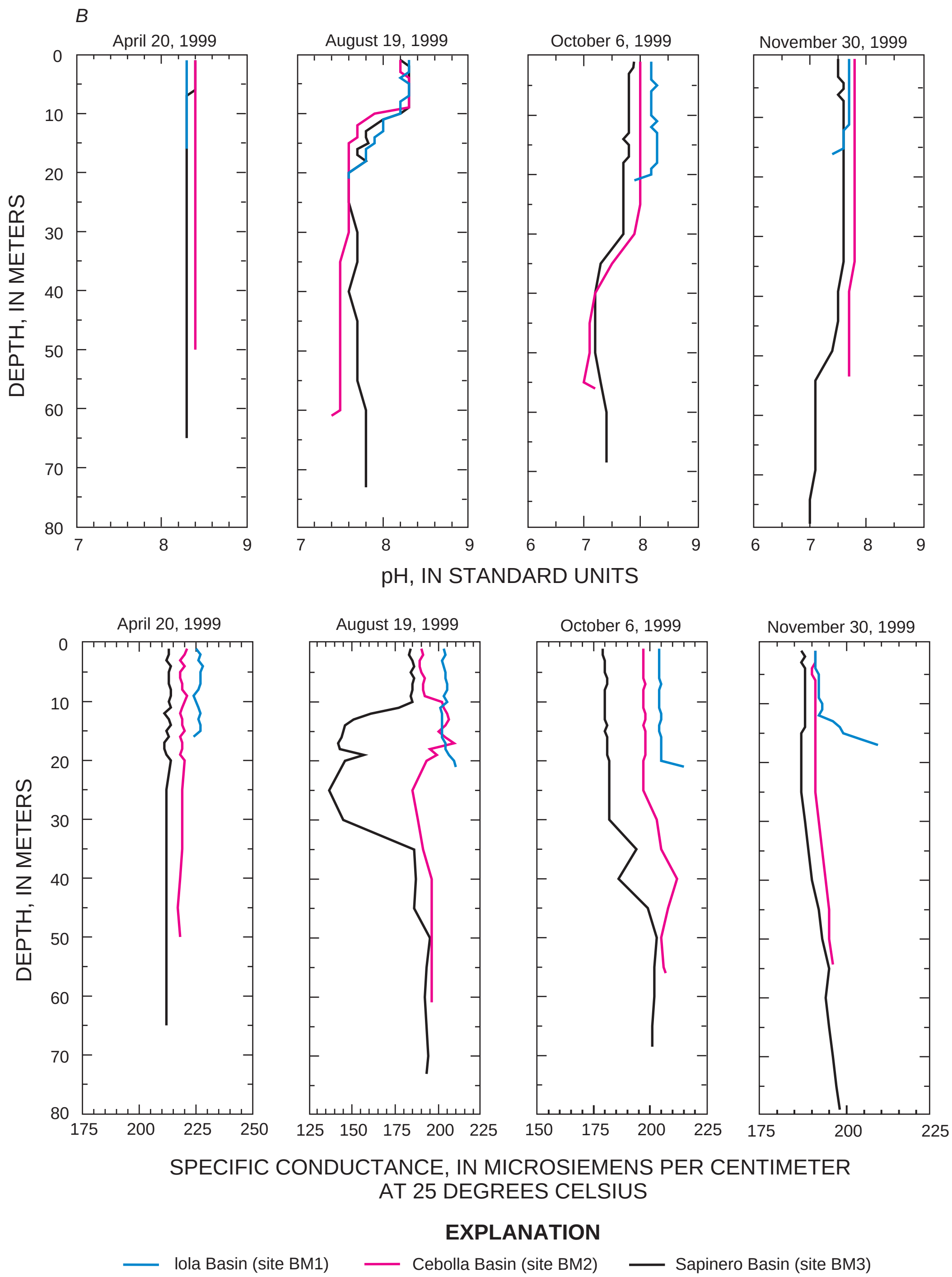

Figure 4. Depth profiles of (*A*) water temperature and dissolved oxygen, and (*B*) pH and specific conductance, Blue Mesa Reservoir, April–November 1999—Continued.

though, specific conductance in Cebolla and Sapinero Basins was more variable. During August, specific conductance in Cebolla Basin was highest in the metalimnion, whereas conductance in Sapinero Basin was lowest in the upper two-thirds of the metalimnion and then increased in the lower one-third of the metalimnion and hypolimnion to values near those in the epilimnion. The low specific conductance in Sapinero Basin may have been the result of inflow of snowmelt runoff moving through the reservoir. Dissolved-solids concentrations typically are diluted in snowmelt runoff, resulting in lower specific-conductance values. During October, conductance in Cebolla and Sapinero Basins varied little with depth except for small changes in the metalimnion.

Light transparency of the water at the surface of Blue Mesa Reservoir varied over the sampling period, with the Secchi depth ranging from 3.0 to 5.0 m (fig. 5, tables 22–24). For each basin, Secchi depth was smallest during spring with mixing conditions. Secondary minimum Secchi-depth values were repeated during fall in Iola Basin because of an algal bloom and also in Sapinero Basin. The time of maximum Secchi depth varied among the basins. Average light transparency (Secchi depth) was lowest for Iola Basin (3.6 m) and similar for Cebolla and Sapinero Basins, 4.2 and 4.1 m, respectively. Using the rule of thumb that the depth of the photic zone is 3.0 times the Secchi depth (Cole, 1983), the photic zone in Blue Mesa Reservoir ranged from 9.0 to 15.0 m.

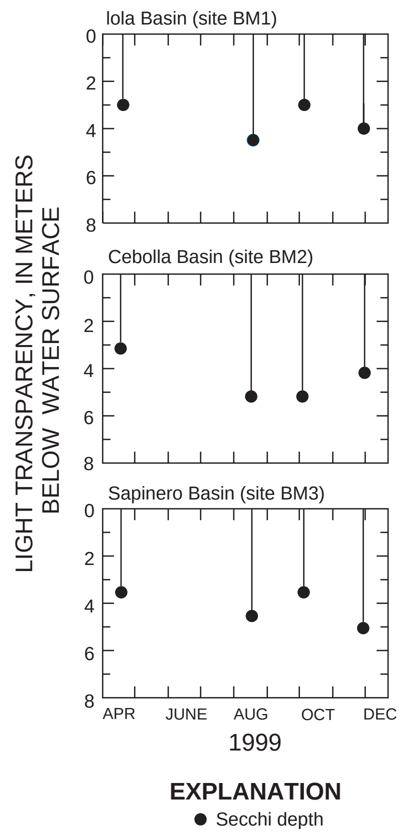

Figure 5. Light transparency in Blue Mesa Reservoir, April–November 1999.

Nutrients

Concentrations of nitrogen nutrient species in Blue Mesa Reservoir were very low throughout the study period. Total nitrogen concentrations, calculated as the sum of total ammonia plus organic nitrogen and dissolved nitrate plus nitrite, ranged from 0.1 to 0.4 mg/L (fig. 6, table 25). Most total nitrogen was in the organic form, which primarily occurs in aquatic ecosystems as organic detritus and plant or animal nitrogen (Horne and Goldman, 1994). Dissolved inorganic nitrogen concentrations, calculated as the sum of dissolved ammonia and dissolved nitrate plus nitrite, ranged from less than 0.005 to 0.16 mg/L (fig. 6, table 25); most was in the nitrate form. Inorganic nitrogen concentrations were at a maximum in spring near the surface of the photic zone. Summer and fall concentrations in the epilimnion were at or below the reporting level of 0.005 mg/L. During these latter times, inorganic nitrogen was essentially fully utilized by phytoplankton. Concentrations of dissolved inorganic nitrogen in many bottom-water samples were higher than the concentrations in the photic zone or epilimnion, with some concentrations being greater by one or two orders of magnitude (fig. 6). For each basin, nitrogen concentrations at depth were highest during stratification. These high concentrations may indicate the settling of decomposing material from the photic zone. Nitrate, nitrite, and un-ionized ammonia concentrations in the reservoir were lower than Colorado water-quality standards by at least one or two orders of magnitude (table 6). Un-ionized ammonia (NH_3) concentrations were estimated from the ammonia concentrations cited in this report (tables 25, 30, 34, 37, 39, and 42) using pH, temperature, and an equilibrium constant (U.S. Geological Survey Office of Water Quality Technical Memorandum No. 93.12, 1993, URL http://water.usgs.gov/admin/memo/QW/qw93.12.html, accessed February 7, 2002).

Concentrations of phosphorus nutrient species also were low in Blue Mesa Reservoir throughout the study period. Total phosphorus concentrations ranged from 0.007 to 0.053 mg/L (fig. 6, table 25). Concentrations of dissolved orthophosphate, an inorganic phosphorus and the only form of phosphorus available for uptake by phytoplankton, ranged from less than the reporting level of 0.001 mg/L to 0.041 mg/L (fig. 6, table 25). In the upper strata of Blue Mesa Reservoir, much of the phosphorus was in the organic form and could not be used by phytoplankton for growth. Most orthophosphate concentrations in the upper strata of the reservoir were less than or equal to 0.004 mg/L for the entire sampling period, reflecting consumption by phytoplankton. This pattern of consistently low orthophosphate concentrations throughout the year was unlike that for dissolved inorganic nitrogen, which had much higher concentrations in spring than during summer, fall, and early winter. The orthophosphate that accumulates during winter is usually reduced by late spring to levels well below that needed by phytoplankton for growth (Horne and Goldman, 1994). During active cell growth of phytoplankton, most of the dissolved inorganic phosphorus that is needed for growth is continually recycled back to phytoplankton through excretion from fish, zooplankton, and bacterial activity and is in the form of soluble phosphate ions (Wetzel, 1983). As with total nitrogen and dissolved inorganic nitrogen, the higher concentrations of total phosphorus and dissolved inorganic phosphorus (orthophosphate) in Blue Mesa Reservoir tended to be present in the hypolimnion during stratification (fig. 6), probably resulting from the decomposition of organic matter.

N:P ratios were estimated, where possible, for each basin in Blue Mesa Reservoir (table 12). Dissolved inorganic nitrogen and orthophosphate concentrations in near-surface and epilimnion samples indicate that phosphorus was the limiting nutrient during spring and nitrogen was the limiting nutrient during early winter for each basin. Although N:P ratios could not be determined for Sapinero Basin during summer or for all three basins during fall, nitrogen probably was the limiting nutrient. For these instances, dissolved inorganic nitrogen concentrations in the near-surface zone or epilimnion were less than the reporting level of 0.005 mg/L, and the corresponding dissolved orthophosphate concentrations were greater than or equal to the reporting level of 0.001 mg/L. N:P ratios could not be determined for Iola and Cebolla Basins for summer, as both dissolved inorganic nitrogen and orthophosphate concentrations were less than the respective reporting levels. For these basins, nitrogen and phosphorus were essentially fully utilized by biological activity during summer.

Phytoplankton

In Blue Mesa Reservoir, phytoplankton densities differed across the sampling period for the three basins. Phytoplankton densities were at a minimum in each basin during summer when nutrient concentrations were low, whereas the time of maximum density differed for each basin (fig. 7, table 27). The extreme phytoplankton density of 21,930 algal units/L in Iola Basin during fall was due almost entirely to the bloom of the blue-green algae *Aphanizomenon* sp. This phytoplankton and *Anabaena* sp., another blue-green algae detected in Curecanti NRA, are able to convert atmospheric nitrogen to ammonia for use as a food source when inorganic nitrogen in a lake or reservoir is depleted. The inorganic nitrogen concentration in the epilimnion of Iola Basin during fall was less than 0.005 mg/L. While *Aphanizomenon* sp. also was dominant or co-dominant in Cebolla and Sapinero Basins during fall, the densities were much smaller, 707 and 66 algal units/L, respectively. Overall, phytoplankton densities generally were highest in Iola Basin and lowest in Sapinero Basin.

Cebolla and Sapinero Basins had mostly similar patterns in genera richness (number of genera present) as compared to Iola Basin (fig. 8). Genera richness in the two downstream basins was greatest during October, with the nine genera detected in each basin being the most for any site in all three reservoirs. Genera richness in Iola Basin was at a minimum during fall because of the dominance of the blue-green algae *Aphanizomenon* sp.

The phytoplankton community in Blue Mesa Reservoir was dominated by diatoms and blue-green algae, with small populations of golden-brown algae, green algae, and dinoflagellates present during the sampling periods (fig. 9). The major components of phytoplankton community succession were mostly similar for the three basins (fig. 10). The spring phytoplankton community in the reservoir consisted

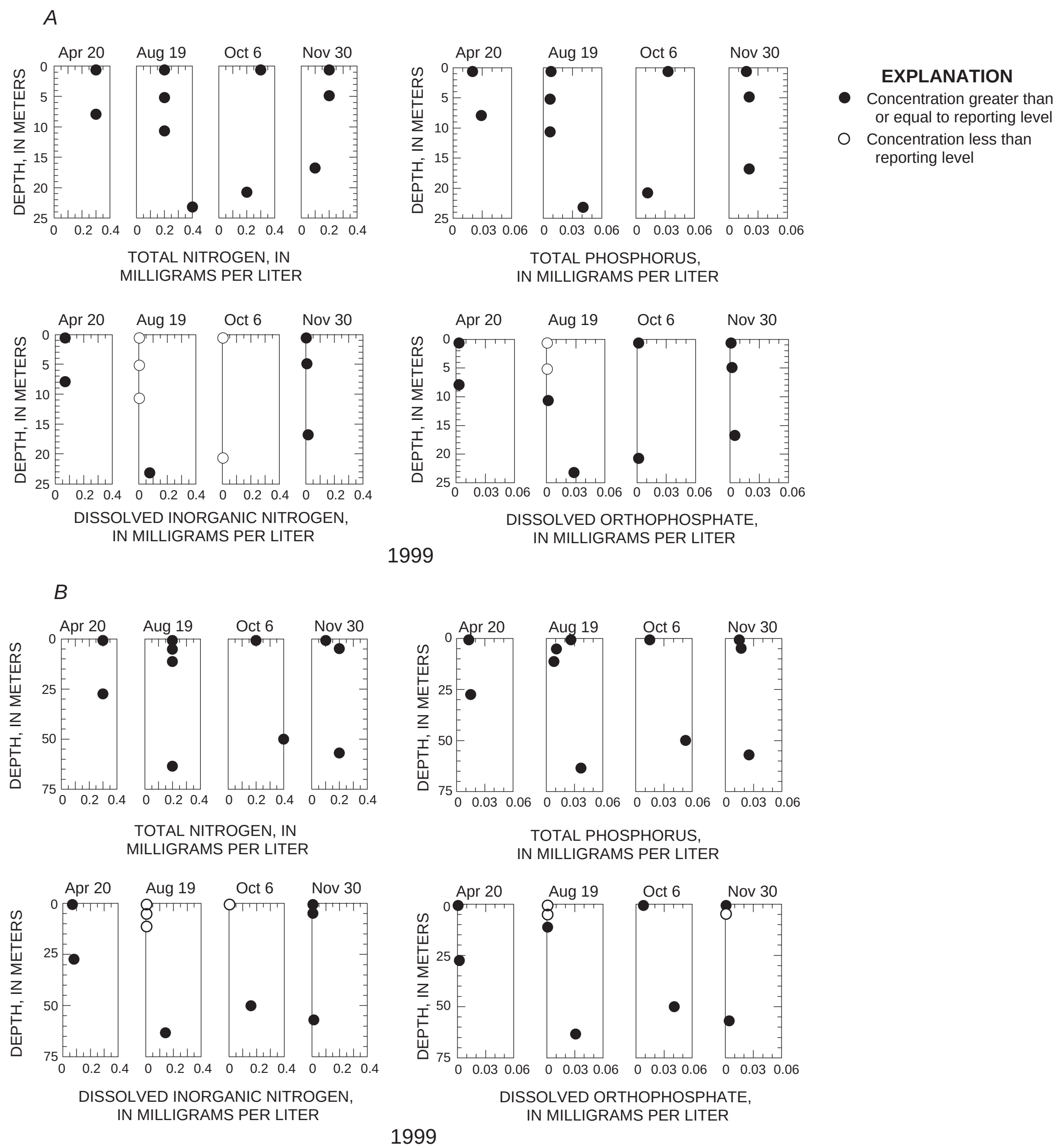

Figure 6. Nitrogen and phosphorus concentrations in Blue Mesa Reservoir at (*A*) Iola Basin (site BM1), (*B*) Cebolla Basin (site BM2), and (*C*) Sapinero Basin (site BM3), April–November 1999.

primarily of diatoms, with *Asterionella* being the dominant genus, and smaller populations of golden-brown algae. During summer, warmer water temperatures and the lack of inorganic nitrogen resulted in the dominance of blue-green algae—*Aphanizomenon* sp. in Iola and Sapinero Basins and *Aphanizomenon* sp. and *Anabaena* sp. in Cebolla Basin—with diatoms, green algae, and a dinoflagellate also present. *Aphanizomenon* sp. was the dominant phytoplankton in Iola Basin during fall, almost to the complete exclusion of other genera. It also was dominant in Cebolla Basin.

The phytoplankton community structure in Sapinero Basin during fall differed from that in the two upstream basins. *Aphanizomenon* sp. and *Tabellaria* sp. each were about one-third of the population, followed by the diatom *Fragilaria* sp. and the green algae *Pandorina* sp. The early winter phytoplankton population in the reservoir was dominated by the diatom *Melosira* sp., accounting for least 81 percent of the population in each basin, followed by *Tabellaria* sp.

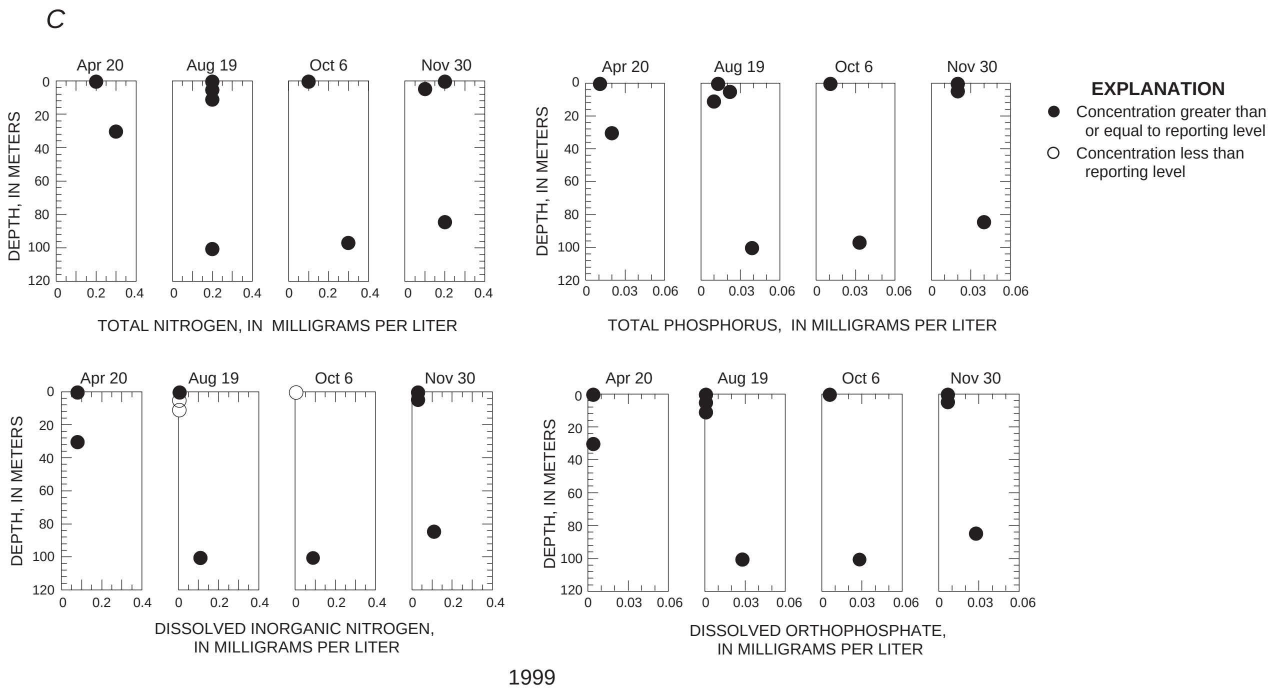

Figure 6. Nitrogen and phosphorus concentrations in Blue Mesa Reservoir at (*A*) Iola Basin (site BM1), (*B*) Cebolla Basin (site BM2), and (*C*) Sapinero Basin (site BM3), April–November 1999—Continued.

Chlorophyll-*a*

In Blue Mesa Reservoir, chlorophyll-*a* concentrations ranged from 0.86 mg/m^3 in Cebolla Basin to 7.55 mg/m^3 in Iola Basin (table 28). The mean chlorophyll-*a* concentration was greatest for Iola Basin (4.55 mg/m^3), followed by Cebolla Basin (3.93 mg/m^3) and Sapinero Basin (2.77 mg/m^3). Each basin had minimum chlorophyll-*a* concentrations during August, corresponding to the time of lowest phytoplankton densities. The time of maximum chlorophyll-*a* concentration varied for each basin. In Iola Basin, the maximum chlorophyll-*a* concentration was at the same time as maximum phytoplankton density—both during October when *Aphanizomenon* sp. was blooming; however, there was no statistical correlation. Chlorophyll-*a* concentrations and phytoplankton densities were positively correlated for Cebolla and Sapinero Basins, as measured by the rank Kendall correlation coefficient at a significance level of $p \leq 0.05$. Correlation between chlorophyll-*a* concentration and phytoplankton density can differ or be nonexistent, in the case of Iola Basin, because the chlorophyll-*a* content varies among algal species and can vary within a single species depending on such factors as light intensity or the availability of nutrients. Using the mean chlorophyll-*a* concentrations listed above and Likens' (1975) chlorophyll-*a* classification system, Iola and Cebolla Basins would be classified as mesotrophic for the entire sampling period, and Sapinero Basin would be oligotrophic. As a whole, Blue Mesa Reservoir would be classified as mesotrophic.

Trophic-state indices (TSI) for total phosphorus, chlorophyll-*a*, and Secchi depth were calculated for each basin and sampling event. The total phosphorus TSI was highest at times in Iola Basin (34–55) as compared to Cebolla (41–51) and Sapinero Basins (39–47) (fig. 11, table 28). An upstream to downstream gradient also applied to the chlorophyll-*a* TSI—Iola Basin (35–50), Cebolla Basin (29–50), and Sapinero Basin (34–45). The Secchi depth TSI was similar (37–44) for the three basins. Ideally, TSI values for a site should be the same for each index parameter for a particular sample. The exception to this in Blue Mesa Reservoir occurred in Cebolla Basin in summer, as the chlorophyll-*a* and Secchi depth indices were less than the total phosphorus index (fig. 11). This could be due to a number of factors, including nutrient limitations, predation on phytoplankton, and variable chlorophyll-*a* content among algal species.

Table 12. Nitrogen phosphorus ratios in Blue Mesa, Morrow Point, and Crystal Reservoirs, April–December 1999

[N:P, nitrogen:phosphorus; nd, not determined]

Date	N:P
BLUE MESA RESERVOIR AT IOLA BASIN (SITE BM1)	
04/20/99	23
08/19/99	nd
10/06/99	nd
11/30/99	5
BLUE MESA RESERVOIR AT CEBOLLA BASIN (SITE BM2)	
04/20/99	70
08/19/99	nd
10/06/99	nd
11/30/99	7
BLUE MESA RESERVOIR AT SAPINERO BASIN (SITE BM3)	
04/20/99	20
08/19/99	nd
10/06/99	nd
11/30/99	4
MORROW POINT RESERVOIR ABOVE PINE CREEK (SITE MP1)	
04/21/99	16
08/23/99	5
10/12/99	3
12/01/99	4
MORROW POINT RESERVOIR AT KOKANEE BAY (SITE MP2)	
04/21/99	16
08/17/99	nd
10/12/99	3
12/01/99	4
MORROW POINT RESERVOIR OFF HERMITS REST (SITE MP3)	
04/21/99	13
08/17/99	nd
10/12/99	3
12/01/99	4
CRYSTAL RESERVOIR NEAR CRYSTAL DAM (SITE CR1)	
04/20/99	14
08/24/99	nd
10/13/99	2
12/02/99	4

Characteristics of Reservoir Inflows

The data discussed in this section for Blue Mesa Reservoir inflow and outflow sites are listed in tables 29–30 in the “Supplemental Data” section at the back of this report.

Physical Properties and Suspended Sediment

Streamflow in the Blue Mesa Reservoir inflows was dominated by snowmelt runoff during spring (table 29). Smaller streamflows at other times of the year reflected the gradual melting of annual snowfields, precipitation events (primarily thunderstorms in summer), and base flow from ground-water discharge. Of the 10 inflow stream sites for Blue Mesa Reservoir sampled for this study (fig. 1, table 1), the Gunnison River (site BI1) provided more than 50 percent of the reservoir inflow for each of the four sampling periods, followed by Lake Fork of the Gunnison River (site BI10) and Cebolla Creek (site BI9) (table 13).

Water temperature in the inflows ranged from –0.4 to 16.5°C, and the median was 8.3°C (table 29). Temperatures reflected a seasonal cycle, with the warmest water during August, followed by May/June or October and November/December (the coolest water). No one inflow had extremes in water temperature.

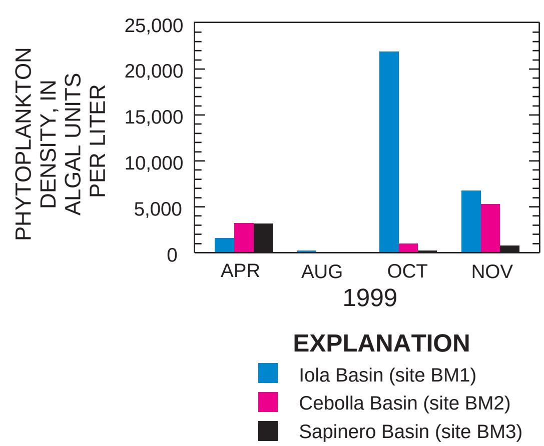

Figure 7. Phytoplankton density in Blue Mesa Reservoir, April–November 1999.

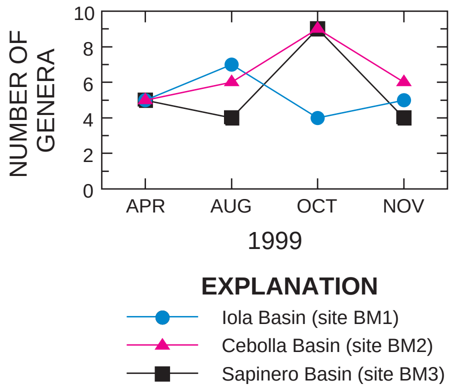

Figure 8. Genera richness in Blue Mesa Reservoir, April–November 1999.

Blue Mesa Reservoir inflows were well oxygenated (table 29). Most dissolved-oxygen concentrations were within a few percentage points (plus or minus) of full saturation for all sampling periods, indicating favorable conditions for aquatic organisms. All concentrations were above the Colorado aquatic-life instream standard (table 6). The well-oxygenated conditions in the tributaries are consistent with dissolved-oxygen concentrations found in other high-gradient streams in the Southern Rocky Mountains physiographic province in Colorado because of generally low water temperatures year-round, shallow stream depths, and high stream velocities promoting the dissolution of oxygen into the stream.

In the inflows, pH indicated slightly basicity conditions. Excluding South Willow Creek, Gunnison River at County Road 32 and Lake Fork of the Gunnison River were the most basic, with median pH values of 8.0 (table 29). High pH can be of concern because the toxicity of un-ionized ammonia to fish increases with higher values for pH; however un-ionized ammonia concentrations in the Gunnison River and Lake Fork were low (undetected or below 0.01 mg/L) and limited any chance of un-ionized ammonia toxicity. All pH values were within the Colorado instream standard (table 6).

Low to moderate amounts of dissolved solids were contributed to Blue Mesa Reservoir by the inflows. Ninety percent of the specific-conductance values were below 205 μS/cm (table 29), reflecting the fact that the inflow drainage basins are primarily underlain by weather-resistant igneous and metamorphic rocks. The highest specific-conductance values were detected in South Willow Creek, an ephemeral stream, and Gunnison River at County Road 32, a large drainage that includes urban and agricultural lands. Inflow streams on the north side of Blue Mesa

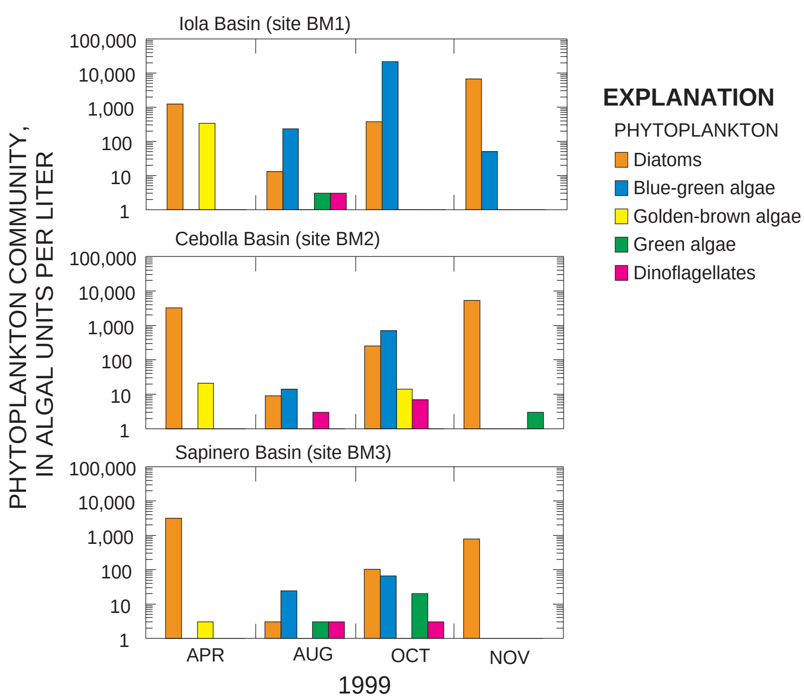

Figure 9. Phytoplankton community in Blue Mesa Reservoir, April–November 1999.

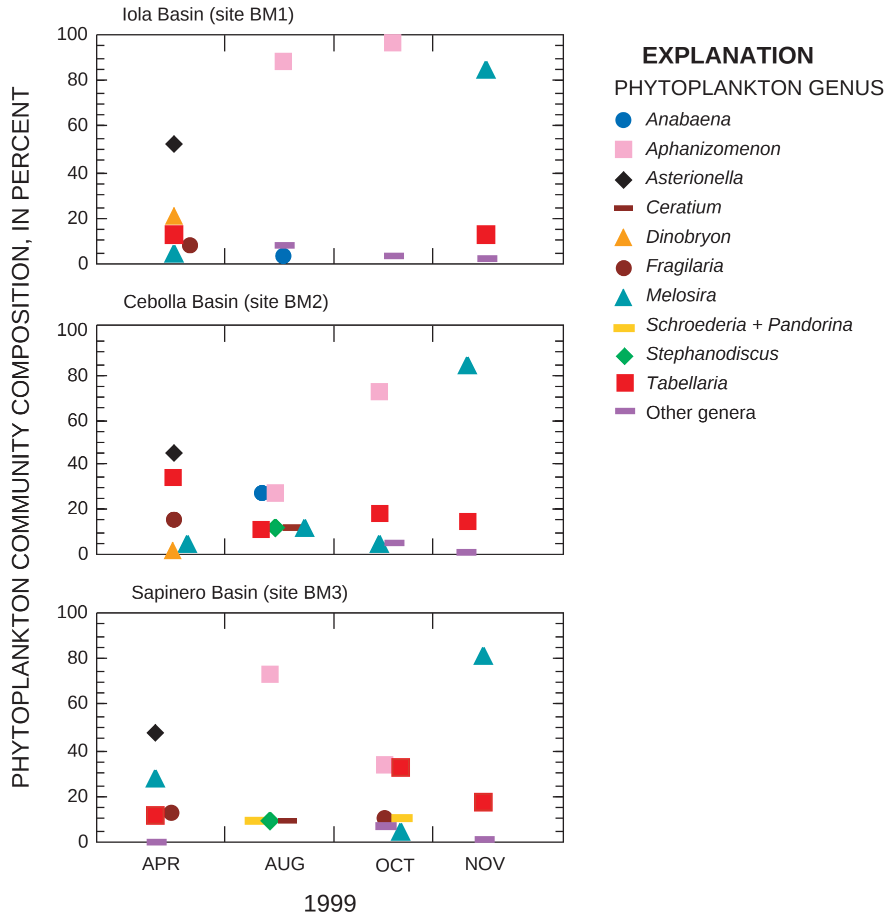

Figure 10. Percent composition of phytoplankton community by genera, Blue Mesa Reservoir, April–November 1999.

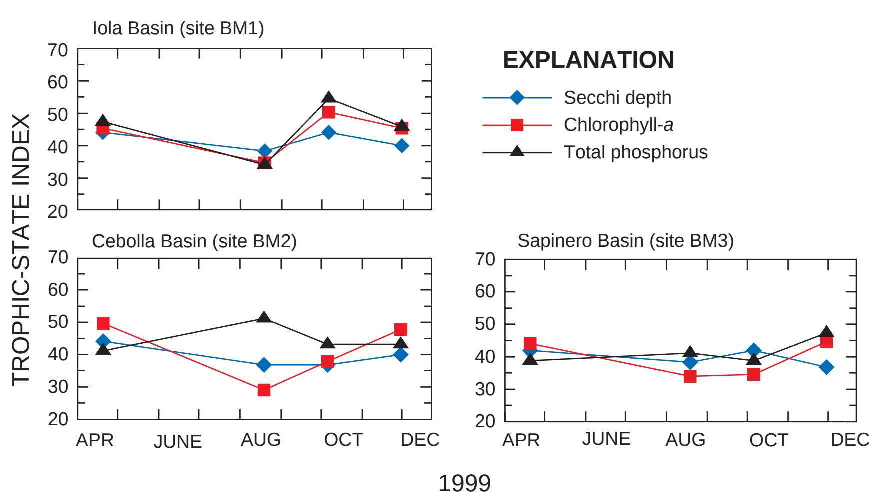

Figure 11. Trophic-state indices for Blue Mesa Reservoir, calculated from Secchi depth, chlorophyll-*a*, and total phosphorus, April–November 1999.

Table 13. Percentage of total inflow into Blue Mesa Reservoir for each sampled inflow site, May–December 1999

[Site number refers to table 1 and figure 1; columns may not add to 100 because of rounding; --, no flow in streambed]

Inflow site	Percentage of total reservoir inflow			
	May/June	August	October	November/December
Gunnison River at County Road 32 (site BI1)	59	54	70	72
Beaver Creek (site BI2)	1.3	1.3	0.67	0.59
Steuben Creek (site BI3)	0.81	0.71	0.40	0.52
East Elk Creek (site BI4)	0.59	0.26	0.30	0.66
Red Creek (site BI5)	0.20	0.04	0.10	0.24
West Elk Creek (site BI6)	1.8	0.77	0.62	1.1
Soap Creek (site BI7)	5.4	1.3	1.5	3.3
South Willow Creek (site BI8)	0.07	--	--	--
Cebolla Creek (site BI9)	9.5	16	9.0	7.9
Lake Fork of the Gunnison River (site BI10)	21	26	18	14

Reservoir drain mostly undeveloped or wilderness lands and contributed few dissolved solids to the reservoir. In most streams, specific conductance was lowest during spring because of dilution by snowmelt and highest during early winter because most streamflow was derived from ground-water discharge.

Concentrations of suspended sediment entering Blue Mesa Reservoir from the inflows were low overall (median of 5 mg/L) and were not a water-quality concern (table 29). Concentrations were largest during spring. Most of the sediment load into the reservoir was supplied by those inflows with higher streamflows and suspended-sediment concentrations. For the four sampling periods, almost 95 percent of the suspended-sediment load to the reservoir was supplied by the three largest tributaries: Gunnison River at County Road 32 (59 percent), Lake Fork of the Gunnison River (24 percent), and Cebolla Creek (12 percent).

Nutrients

Nitrogen concentrations were low in the inflows. Concentrations of total nitrogen (the sum of dissolved nitrate plus nitrite and total organic nitrogen plus ammonia) ranged from 0.05 to 0.5 mg/L with the highest concentrations primarily in spring during snowmelt (table 30). Median concentrations of total nitrogen generally were higher in the larger inflows and the small inflow from Red Creek. Dissolved inorganic nitrogen concentrations (the sum of nitrate plus nitrite and ammonia) in the inflows were much lower than total nitrogen, ranging from less than 0.005 to 0.088 mg/L (table 30), indicating that most of the nitrogen supplied to the reservoir by the inflows was organic nitrogen. For most sampling periods, nitrate was detected in higher concentrations than ammonia and was the dominant form of inorganic nitrogen. Maximum concentrations of nitrate and ammonia were low, 0.082 and 0.014 mg/L, respectively (table 30). All nitrite, nitrate, and un-ionized ammonia concentrations in the inflows to Blue Mesa Reservoir were much lower than the Colorado instream water-quality standards (table 6). Prior sampling at Gunnison River at County Road 32 showed that the maximum nitrate plus nitrite concentrations commonly occurred prior to peak flows from snowmelt runoff in spring. Concentrations were diluted by snowmelt and increased again the following winter (Spahr and others, 2000).

Total phosphorus concentrations in the inflows ranged from 0.022 to 0.2 mg/L (table 30). The maximum concentration was in East Elk and Red Creeks, both of which drain mostly undeveloped forest land. Seventy percent of the inflow samples had total phosphorus concentrations above 0.05 mg/L, indicating that high concentrations frequently entered the reservoir during the four sampling periods. Each inflow had at least one sample above 0.05 mg/L, and all or most samples from Cebolla Creek and all north-side tributaries (excluding Soap Creek) had concentrations exceeding 0.05 mg/L. Higher total phosphorus concentrations in the smaller inflows were unexpected because total phosphorus concentrations in mostly forested or pristine areas of the Nation generally are less than 0.02 mg/L (Litke, 1999). Decomposing organic matter from beaver ponds located upstream from the inflow sampling sites may be the source of the additional total phosphorus. For Beaver, East Elk, and Red Creeks, the highest percentage of particulate phosphorus in the sample water occurred during fall. For all other stream inflows, the highest percentage of particulate phosphorus occurred during spring. Gunnison River at County Road 32 and Cebolla Creek were the only inflows where particulate phosphorus was more than 50 percent of the total phosphorus in two or more samples. Orthophosphate, the primary component of dissolved phosphorus and the form of phosphorus used by phytoplankton, was detected in the inflows in concentrations ranging from 0.004 to 0.14 mg/L (table 30). In general, orthophosphate accounted for over 50 percent of total phosphorus in those inflows with low suspended-sediment concentrations.

Because phosphorus usually is the limiting nutrient in lakes and reservoirs, excessive phosphorus in streams can lead to eutrophication in water bodies. To control eutrophication, the USEPA established a recommended limit for total phosphorus of 0.05 mg/L in rivers and streams that enter lakes and reservoirs (U.S. Environmental Protection Agency, 1986). While most samples from the Blue Mesa Reservoir inflows had total phosphorus concentrations above 0.05 mg/L, the effects on the reservoir would be small because of the relatively small volumes of inflow from the smaller streams.

As discussed in the “Data Collection and Analysis Methods” section, monthly nutrient loads for the Blue Mesa Reservoir inflows could only be determined for Gunnison River at County Road 32 (site BI1). For all other sites, lack of nutrient and streamflow data limited monthly load calculations. For site BI1, estimated mean annual and monthly discharge and loads in kilograms per day for total nitrogen, dissolved inorganic nitrogen, total phosphorus, and dissolved orthophosphate for 1995–99 are listed in table 14. Mean annual and monthly loads were highest for total nitrogen and lowest for dissolved orthophosphate. Mean monthly loads varied seasonally and were largest during the snowmelt runoff months of May, June, and July. Loads from the other inflows would have a similar pattern of seasonal variation.

Characteristics of Reservoir Outflow

Outflow from Blue Mesa Reservoir ranged from 1,317 to 3,263 ft^3/s for the four sampling periods (table 29). Higher releases generally occurred during the warmer months (fig. 3). Water temperature ranged from 6.0°C during early winter to 12.5°C during fall and reflected cold hypolimnetic discharge from the

Table 14. Estimated mean annual and monthly discharge and nutrient loads for Gunnison River at County Road 32 (site BI1), calendar years 1995–99

[Site number refers to table 1 and figure 1; acre-ft/d, acre-foot per day; kg/d, kilograms per day]

Month	Mean discharge (acre-ft/d)	Mean load (kg/d)			
		Total nitrogen	Dissolved inorganic nitrogen	Total phosphorus	Dissolved orthophosphate
January	646	160	81	26	15
February	644	210	87	32	16
March	853	360	110	54	21
April	1,696	870	210	140	37
May	4,980	2,900	540	490	87
June	7,049	3,700	640	640	110
July	4,227	1,700	320	270	65
August	2,254	640	150	92	36
September	1,530	330	99	47	26
October	1,193	220	86	33	21
November	867	160	75	24	17
December	720	150	76	23	15
Annual	2,222	950	200	160	39

reservoir. Dissolved-oxygen concentrations (summer and fall only) and pH met Colorado instream water-quality standards (table 6). Dissolved oxygen was not measured during spring and early winter because of equipment failures. Water released from Blue Mesa Reservoir had moderate specific conductance, from 174 to 200 μS/cm.

The concentration of total nitrogen in the Blue Mesa Reservoir outflow was 0.1 mg/L for all four sampling periods (table 30). Inorganic nitrogen concentrations in the release water were low, from 0.012 mg/L during spring to 0.054 mg/L during summer. More than one-half of the inorganic nitrogen during spring was ammonia, whereas nearly all inorganic nitrogen for the remaining sampling periods was nitrate. Total phosphorus concentrations were consistently low in the reservoir outflow, ranging from 0.014 mg/L during spring to 0.021 mg/L during fall and early winter (table 30). This is in contrast to the higher total phosphorus concentrations detected in the reservoir's stream inflows. Orthophosphate was only detected in very low concentrations in the release waters. Concentrations ranged from 0.005 mg/L during spring to 0.014 mg/L during summer and fall.

LIMNOLOGY OF MORROW POINT RESERVOIR

Reservoir data discussed in this section are located in tables 26, 28 and 31–35 of the "Supplemental Data" section at the back of this report.

Physical Properties

Water temperature in Morrow Point Reservoir ranged from 15.8°C at 1 m below the water surface to 3.9°C at depth (fig. 12*A*, tables 31–33). Water temperatures were influenced by cold water releases from Blue Mesa Reservoir and less sunlight reaching the waters of Morrow Point Reservoir because of the reservoir's steep canyon walls. The site Above Pine Creek (MP1) exhibited isothermal conditions for all four sampling periods (fig. 12*A*, table 31). This site is about 0.5 mile downstream from Blue Mesa Dam and was characterized by riverine conditions with strong flowing current for each sampling period, resulting in well-mixed conditions and no thermal or chemical stratification. Kokanee Bay and Hermits Rest were isothermal during spring and early winter and stratified during summer and fall. At both downstream sites, the epilimnion was thin during summer and thicker and more pronounced during fall. At Hermits Rest, there was a secondary thermal decrease or thermal discontinuity deeper in the water column during summer. Water temperature in Morrow Point Reservoir was cooler than that measured in Blue Mesa Reservoir.

Dissolved-oxygen concentrations in Morrow Point Reservoir were at a maximum of 10.5 mg/L during April when water temperatures were coldest and at a minimum of 3.2 mg/L during December at depth (fig. 12*A*, tables 31–33). Anoxic conditions were not present. Concentrations were mostly uniform throughout the water column during isothermal conditions at Above Pine Creek (all four sampling periods) and during April at Kokanee Bay and Hermits Rest. For the latter two sites, dissolved-oxygen concentrations decreased at depth for the October and December profiles, except for Hermits Rest during October when concentrations increased at depth. August concentrations at these two downstream sites were not obtained because of faulty equipment. Only one dissolved-oxygen concentration, 5.6 mg/L in the metalimnion of Kokanee Bay during October, did not meet the Colorado water-quality standard for epilimnion and metalimnion strata (table 6).

In Morrow Point Reservoir, pH values ranged from 7.0 to 8.5 standard units (fig. 12*B*, tables 31–33). At each site, pH values throughout the water column were at maximum levels during spring and decreased to minimum levels during fall and early winter. When isothermal conditions were present at a site, pH varied only slightly with depth. Variability increased at Kokanee Bay and Hermits Rest with stratification during August but was much less pronounced during October stratification. All pH values were well within the Colorado water-quality standard (table 6). For each site, no significant correlation existed between pH values and chlorophyll-*a* concentrations, as measured by the rank Kendall correlation coefficient at a significance level of $p \leq 0.05$.

Specific conductance in the reservoir varied from 166 to 212 μS/cm (fig. 12*B*, tables 31–33), equivalent to estimated dissolved-solids concentrations of 100–127 mg/L (conversion factor of 0.6; Hem,

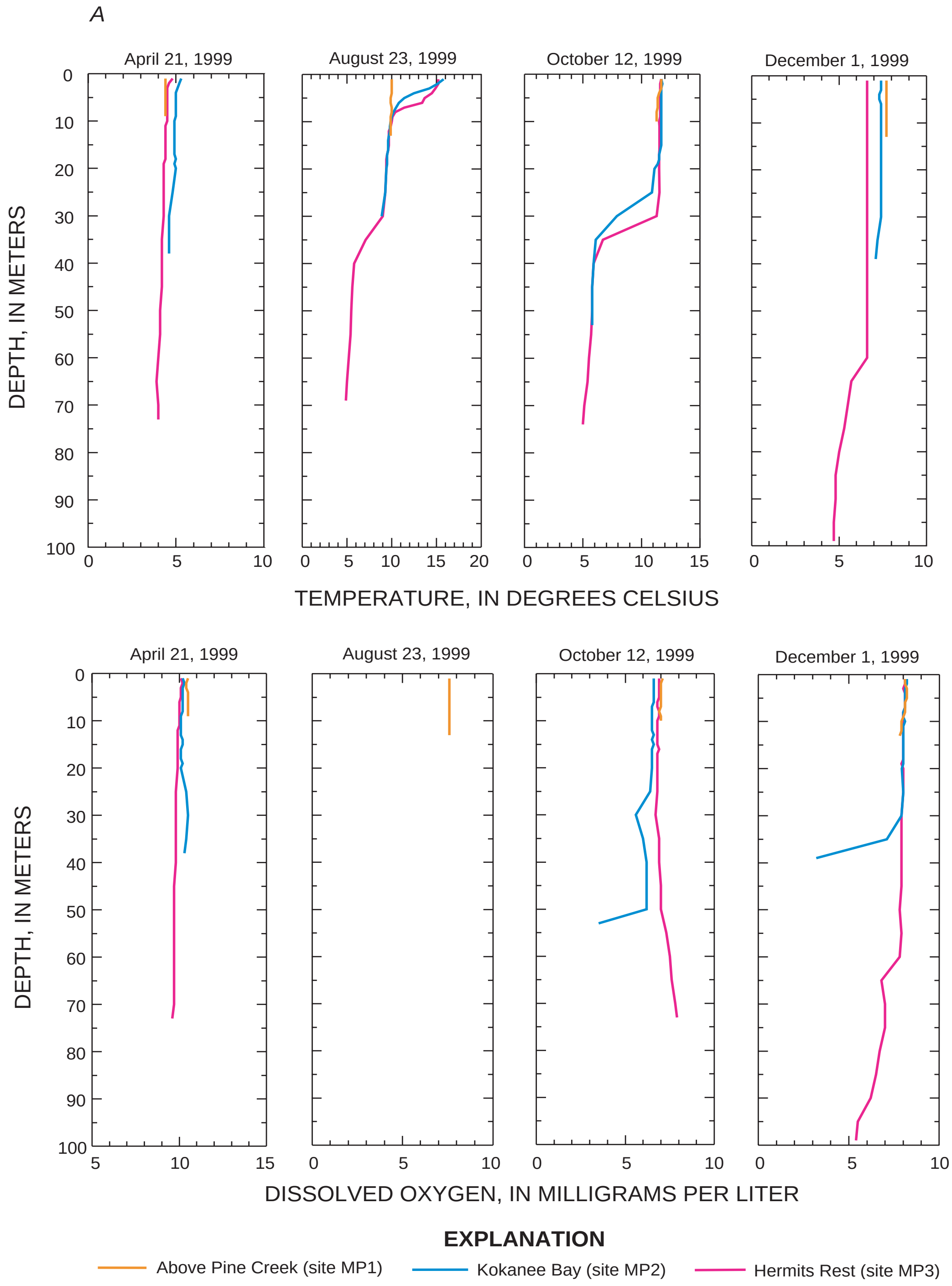

Figure 12. Depth profiles of (*A*) water temperature and dissolved oxygen, and (*B*) pH and specific conductance, Morrow Point Reservoir, April–December 1999.

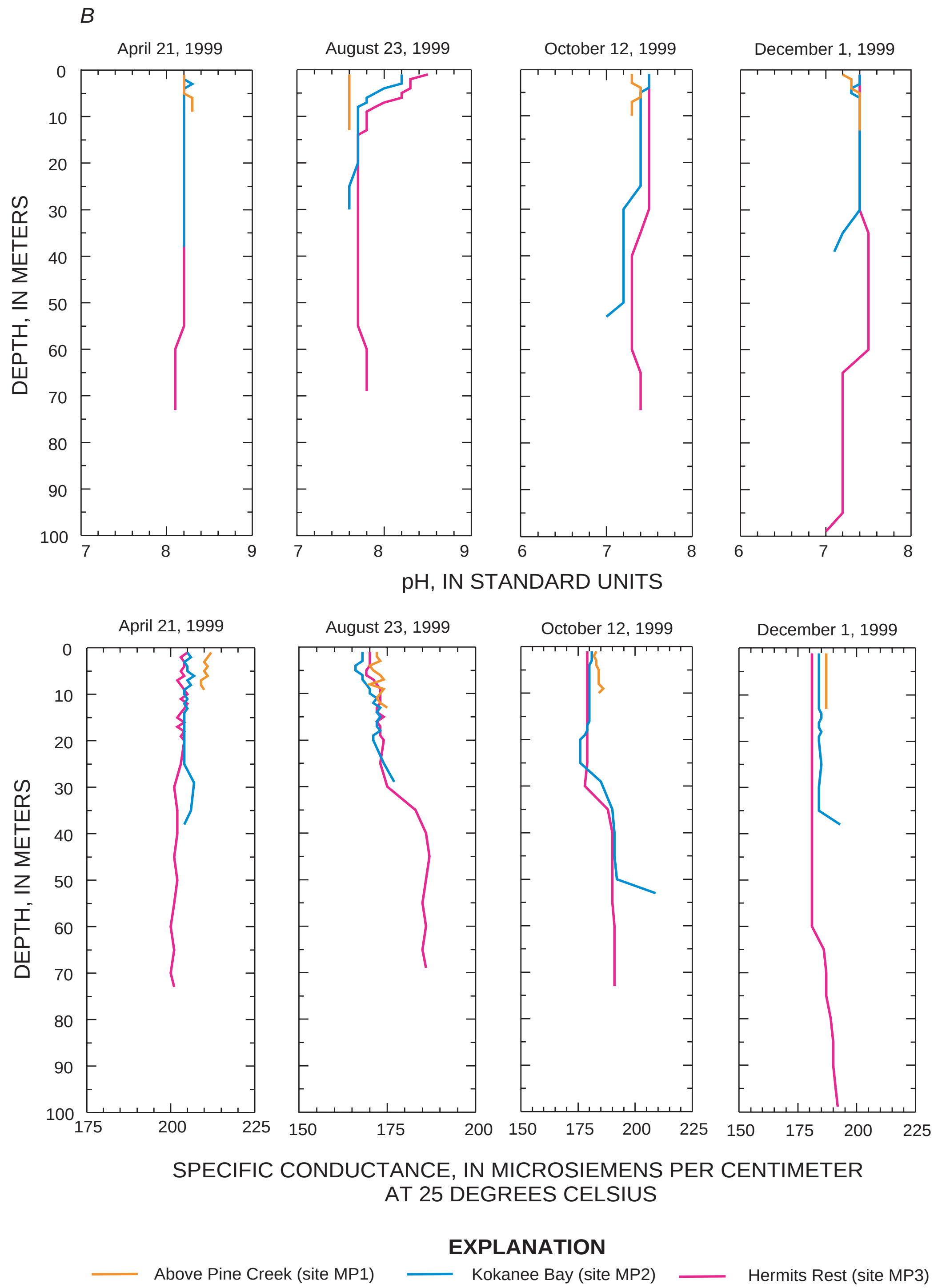

Figure 12. Depth profiles of (*A*) water temperature and dissolved oxygen, and (*B*) pH and specific conductance, Morrow Point Reservoir, April–December 1999—Continued.

1985). These values would indicate dilute conditions. Maximum and minimum specific conductance for each site generally occurred during April and August, respectively. Each site had mostly uniform specific conductance with depth when isothermal conditions were present. Specific conductance was more variable with depth at Kokanee Bay and Hermits Rest with stratification during August and October.

Light transparency in Morrow Point Reservoir ranged from 2.5 to 7.3 m (fig. 13, tables 31–33). Transparency was at a minimum at each site during spring with mixing conditions and again at Hermits Rest during fall. The time of maximum light penetration varied. Mean light transparency for the four sampling periods increased along a downstream gradient in the reservoir, with an average Secchi depth of 3.4 m for Above Pine Creek, 4.1 m for Kokanee Bay, and 5.8 m for Hermits Rest. Transparency at the first site was affected by riverine conditions. Using a photic-zone/Secchi-depth relationship of 3, the photic zone in Morrow Point Reservoir ranged between 7.5 and 21.9 m. Among the three reservoirs, the largest range in light transparency was in Morrow Point Reservoir.

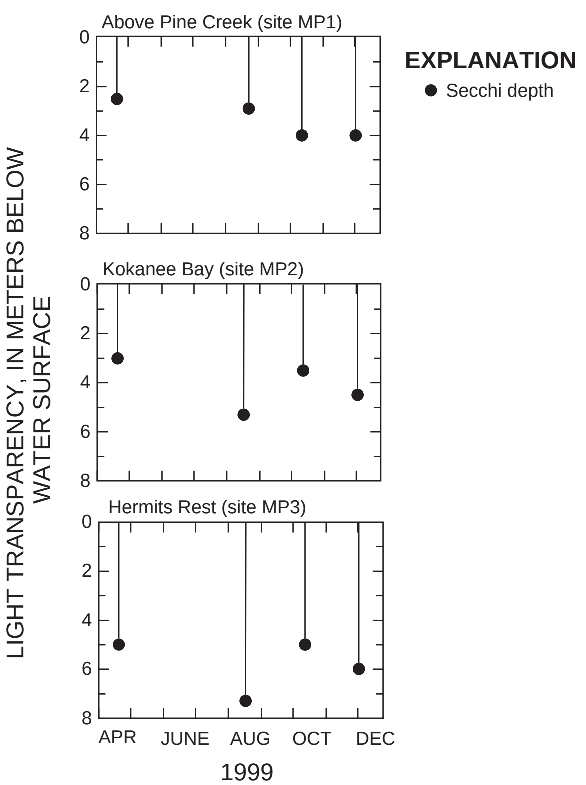

Figure 13. Light transparency in Morrow Point Reservoir, April–December 1999.

Nutrients

Nitrogen concentrations in Morrow Point Reservoir were very low for the study period. Total nitrogen concentrations ranged from 0.1 to 0.3 mg/L, and many concentrations were equal to or less than 0.2 mg/L (fig. 14, table 34). Only the fall and early winter Kokanee Bay samples had higher total nitrogen concentrations at depth than in the photic zone. Nitrogen in the reservoir occurred primarily as organic nitrogen. Dissolved inorganic nitrogen concentrations ranged from less than 0.005 to 0.149 mg/L (fig. 14, table 34). The four summer epilimnion samples for Kokanee Bay and Hermits Rest were the only samples with dissolved inorganic nitrogen concentrations below 0.032 mg/L; all four were less than 0.005 mg/L. Most dissolved inorganic nitrogen was in the form of nitrate. The deeper summer sample at Above Pine Creek was the only sample with an ammonia concentration higher than the corresponding nitrate concentration. For one or more sampling events at each site in Morrow Point Reservoir, the dissolved inorganic nitrogen concentration at depth was higher than the corresponding epilimnion or photic zone concentration. All nitrate, nitrite, and un-ionized ammonia concentrations in Morrow Point Reservoir were at least one order of magnitude lower than Colorado instream water-quality standards (table 6).

Total phosphorus concentrations in Morrow Point Reservoir also were low, ranging from 0.007 to 0.024 mg/L (fig. 14, table 34). Concentrations in bottom-water samples during stratification were at most 0.010 mg/L higher than concentrations in the epilimnion. Dissolved orthophosphate concentrations also were low in Morrow Point Reservoir, ranging from less than the reporting level of 0.001 to 0.018 mg/L (fig. 14, table 34). Concentrations less than or equal to 0.004 mg/L were detected only in the epilimnion of Kokanee Bay and Hermits Rest during summer. Concentrations also were low for all spring samples at the three sites.

Phosphorus was the limiting nutrient for each site during spring, and nitrogen was the limiting nutrient during fall and early winter (table 12). Nitrogen also was the limiting nutrient at Above Pine Creek during summer. Nitrogen was probably the limiting nutrient in Kokanee Bay during summer as inorganic nitrogen concentrations in the epilimnion were less than the laboratory reporting level of

0.005 mg/L and related orthophosphate concentrations were greater than the laboratory reporting level of 0.001 mg/L. Nutrient limitation could not be determined for Hermits Rest during summer. Concentrations of both inorganic nitrogen and orthophosphate in the epilimnion were below the respective laboratory reporting levels; inorganic nitrogen and orthophosphate were essentially fully utilized by biological activities during summer. The spring and early winter limitations of phosphorus and nitrogen, respectively, in Morrow Point Reservoir were similar to those in Blue Mesa Reservoir.

Phytoplankton

Phytoplankton density in Morrow Point Reservoir varied across the sampling period. Densities were smallest during August when nutrients were limited; densities also were low during October (fig. 15, table 35). Maximum phytoplankton density was during early winter at Above Pine Creek and Kokanee Bay and during spring at Hermits Rest. Densities generally were lower at Above Pine Creek than at the two downstream sites. The highest phytoplankton density in Morrow Point Reservoir, 1,264 algal units/L at Kokanee Bay during early winter, was much smaller than the maximum densities of 21,930, 5,304, and 3,177 algal units/L for the Blue Mesa Reservoir sites.

There were few patterns to richness in genera among the Morrow Point Reservoir sites (fig. 16). Genera richness at Above Pine Creek was at a minimum during August with only the diatoms *Melosira* sp. and *Fragilaria* sp. present. Genera richness for Kokanee Bay was constant for spring through fall and then decreased during early winter, whereas genera richness for Hermits Rest decreased from spring to fall. Above Pine Creek had the lowest number of genera present for any site in the three reservoirs. This probably was due to the fast-flowing, riverine conditions that dominate at the site due to its proximity to Blue Mesa Dam.

Diatoms were the dominant community group throughout the year in Morrow Point Reservoir (figs. 17–18). The golden-brown algae *Dinobryon* sp., the green algae *Schroederia* sp. and *Spirogyra* sp., and the blue-green algae *Aphanizomenon* sp. were present only in small amounts during April, August, and(or) October. Dinoflagellates were not detected. The diatom *Melosira* sp. was the most common phytoplankton in about 67 percent (8 of 12) of the Morrow Point Reservoir samples. In five samples, it represented 60 percent or more of the total phytoplankton population. When *Melosira* sp. populations were low during summer at Kokanee Bay and during fall at each site, the diatoms *Fragilaria* sp. and *Tabellaria* sp. were the most common phytoplankton, respectively. In contrast to Blue Mesa Reservoir, *Asterionella* sp. and *Aphanizomenon* sp. were never the most dominant species in any sample from Morrow Point Reservoir.

Phytoplankton density at Kokanee Bay and Hermits Rest differed between 1999 and 1998. Considering spring through fall samples only, densities during 1999 were at a maximum during spring, a minimum during summer, and low during fall, whereas densities during 1998 were low during spring, at a maximum during summer, and a minimum during fall (National Park Service, 1998b). Mean phytoplankton densities at Kokanee Bay and Hermits Rest for spring through fall were lower during 1999 than during 1998—318 and 433 algal units/L, respectively, during 1999 as compared to 989 and 1,030 algal units/L, respectively, during 1998. Phytoplankton density varies from year to year in a water body as environmental conditions vary, but because of limited phytoplankton data for Morrow Point Reservoir, it is not known whether the differences in phytoplankton density and distribution between 1999 and 1998 are significant or are within normal year-to-year variance.

The dominance of diatoms in Morrow Point Reservoir during 1999 also was observed during 1998 (National Park Service, 1998b). However, there were some differences in community structure between the two years. The phytoplankton community during the summer of 1998 was dominated by *Asterionella* sp. and *Melosira* sp.; during 1999, *Melosira* sp. and *Fragilaria* sp. were prevalent during summer and dominant at two of three sites. The diatom *Stephanodiscus* sp. was the only taxon present at Kokanee Bay during fall 1998 and also was included in the community at Hermits Rest, but it was observed only in small populations during 1999. Also, a small population of *Aphanizomenon* sp. was present in the reservoir during fall 1999 but was not detected during 1998. Yearly fluctuations in species compositions such as these are normal in a water body (Wetzel, 1983).

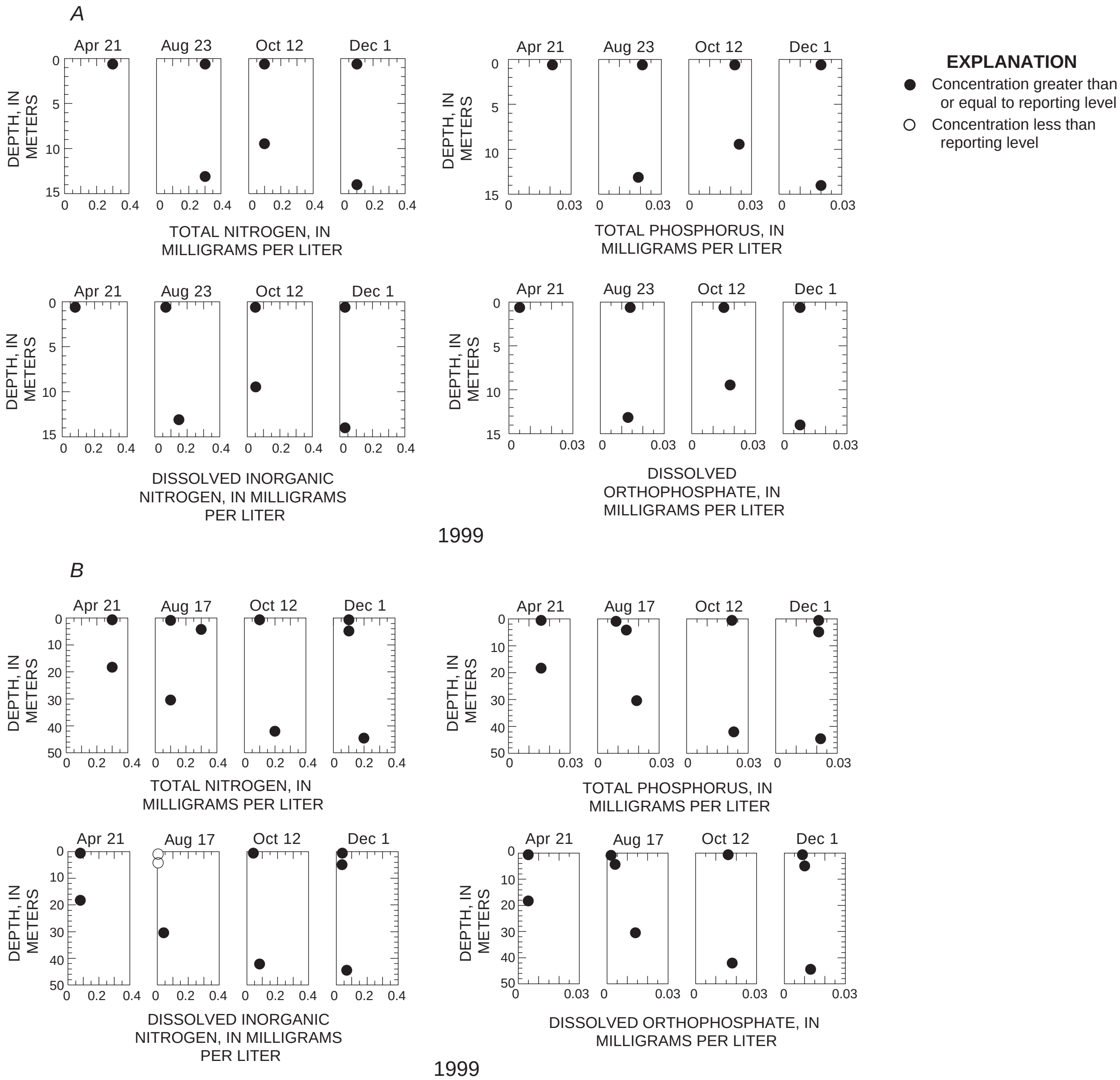

Figure 14. Nitrogen and phosphorus concentrations in Morrow Point Reservoir, (*A*) Above Pine Creek (site MP1), (*B*) Kokanee Bay (site MP2), and (*C*) Hermits Rest (site MP3), April–December 1999.

Chlorophyll-*a*

Chlorophyll-*a* concentrations in Morrow Point Reservoir ranged from 0.91 to 4.39 mg/m^3 (table 28). Mean chlorophyll-*a* concentrations were 2.26 mg/m^3 for Above Pine Creek, 2.36 mg/m^3 for Kokanee Bay, and 2.34 mg/m^3 for Hermits Rest. All three sites were oligotrophic, based on Likens' classification system (Likens, 1975). Chlorophyll-*a* concentrations at Above Pine Creek were smallest during August and largest during December. Concentrations at Kokanee Bay and Hermits Rest were smallest during October and largest during April. The only statistically significant ($p \leq 0.05$) correlation was between chlorophyll-*a* concentration and phytoplankton density for Above Pine Creek. TSI values ranged from 32 to 49 for total phosphorus, 30 to 45 for chlorophyll-*a*, and 31 to 47 for Secchi depth (fig. 19, table 28). Values for a particular site per sampling period were fairly similar except for Above Pine Creek during summer and fall and for Kokanee Bay and Hermits Rest during fall.

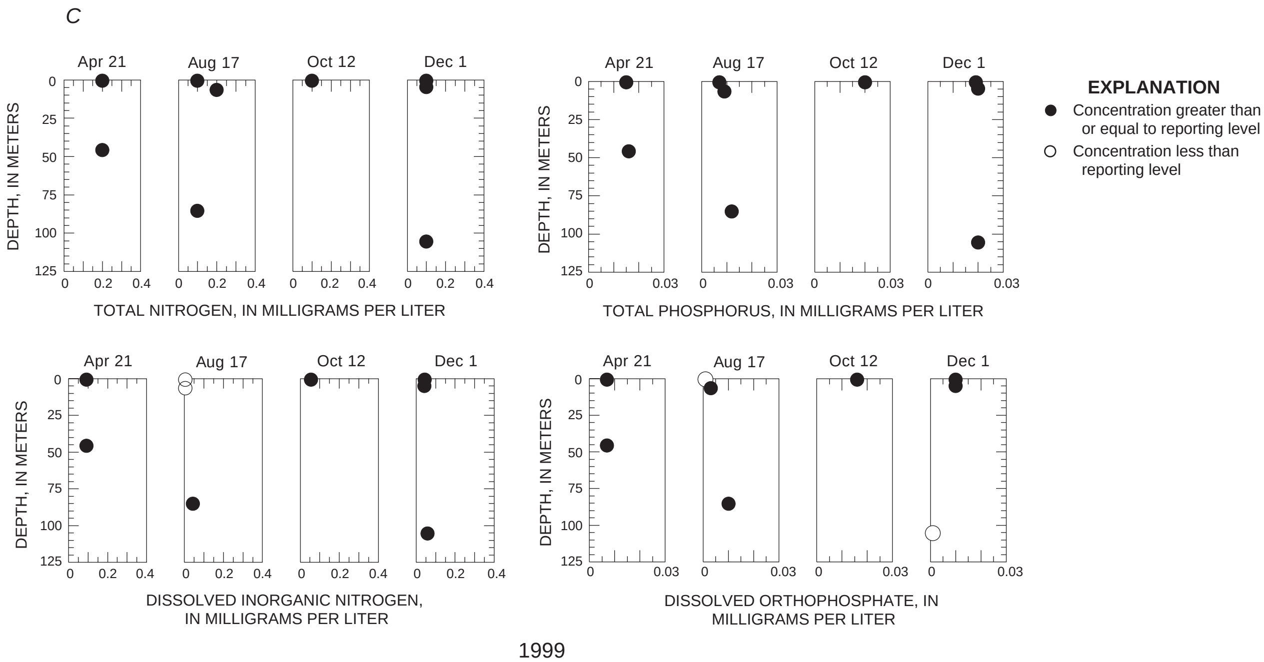

Figure 14. Nitrogen and phosphorus concentrations in Morrow Point Reservoir, (*A*) Above Pine Creek (site MP1), (*B*) Kokanee Bay (site MP2), and (*C*) Hermits Rest (site MP3), April–December 1999—Continued.

Characteristics of Reservoir Inflows

Data discussed in this section are located in tables 36–37 of the “Supplemental Data” section at the back of this report.

Physical Properties and Suspended Sediment

Five inflow sources to Morrow Point Reservoir were studied: the outflow from Blue Mesa Reservoir (site BO) (discussed above in “Characteristics of Reservoir Outflow” for Blue Mesa Reservoir) and four stream inflows (fig. 1, table 1). For the four sampling periods, most (median of 96 percent) of the water flowing into Morrow Point Reservoir was water released from Blue Mesa Reservoir, with the remainder mainly supplied by Blue and Curecanti Creeks (table 15). Streamflow in the inflows ranged from 0.18 to 161 ft^3/s and was highest during spring (table 36).

Water temperature in the stream inflows ranged from 0.0° to 17.0°C, and the median was 6.1°C (table 36). Temperatures varied seasonally. The warmest temperatures were during August, followed by October and(or) May/June and December (the coolest). Blue Creek was consistently cooler than the other inflows for all sampling periods except December.

The inflows to Morrow Point Reservoir were well oxygenated (table 36). Each inflow was almost fully saturated with dissolved oxygen during the four sampling periods, indicating favorable conditions for aquatic organisms. All dissolved-oxygen concentrations met the Colorado instream water-quality standard (table 6).

Median pH in the Morrow Point Reservoir inflows was 7.9 (table 36). There was little chance of un-ionized ammonia toxicity to fish with elevated pH, as all dissolved ammonia concentrations were equal to or less than 0.01 mg/L. All pH values were within the Colorado instream water-quality standard (table 6). Median pH in the Morrow Point Reservoir inflows was slightly more basic than that in the Blue Mesa Reservoir inflows. This may reflect a difference in the geology of the inflow watersheds.

Specific conductance in the inflows ranged from 48 to 141 µS/cm (table 36). As such, low amounts of dissolved solids were supplied to Morrow Point Reservoir. Specific conductance in the Morrow Point Reservoir inflows was diluted during spring because of snowmelt runoff and was more concentrated at other times of the year because of ground-water discharge (base flow), similar to conditions in the inflows to Blue Mesa Reservoir.

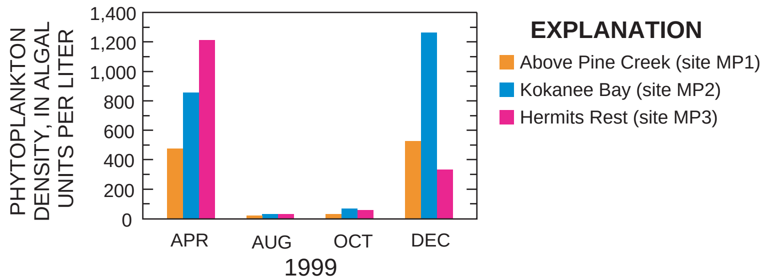

Figure 15. Phytoplankton density in Morrow Point Reservoir, April–December 1999.

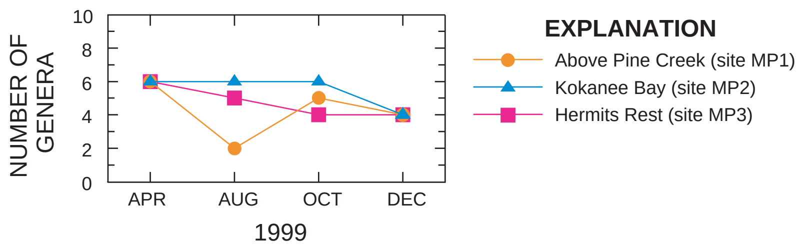

Figure 16. Genera richness in Morrow Point Reservoir, April–December 1999.

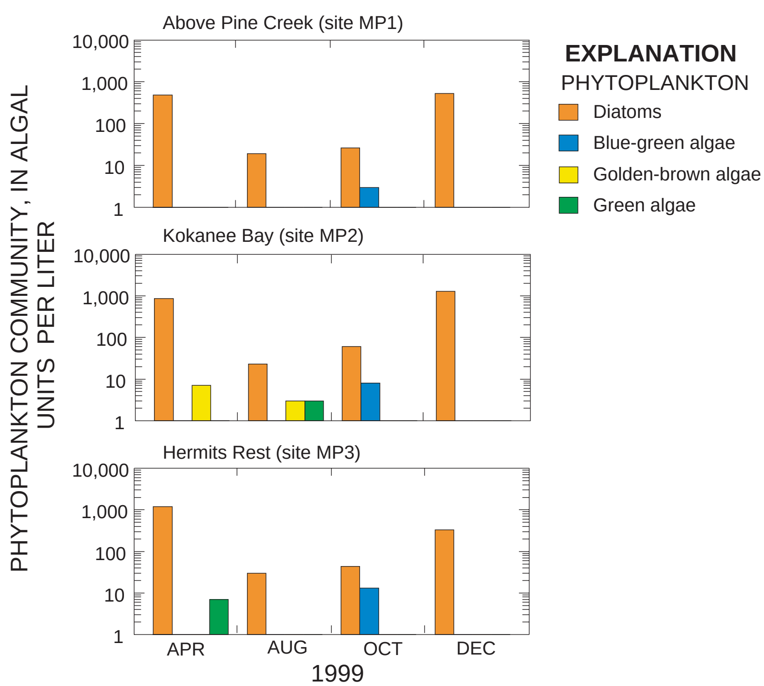

Figure 17. Phytoplankton community in Morrow Point Reservoir, April–December 1999.

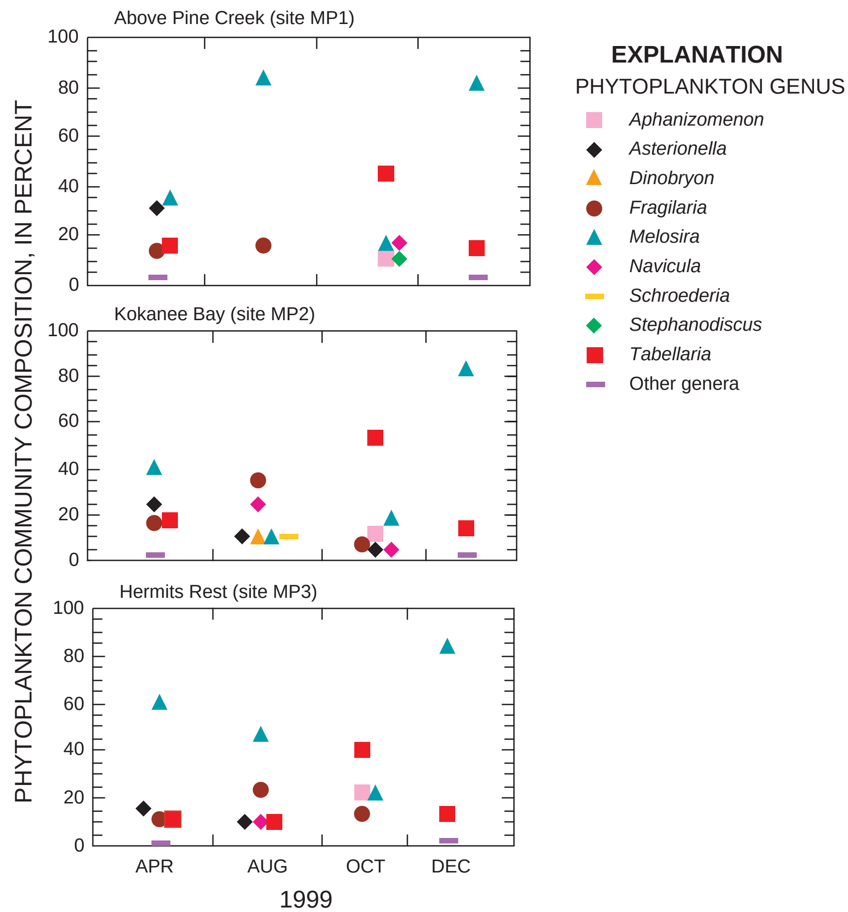

Figure 18. Percent composition of phytoplankton community by genera, Morrow Point Reservoir, April–December 1999.

Suspended-sediment concentrations in the Morrow Point Reservoir inflows were low, ranging from 2 to 31 mg/L (table 36) and did not appear to affect water quality in the reservoir. Concentrations were highest during spring. Most of the suspended-sediment load into Morrow Point Reservoir came from Blue Creek (all four sampling periods) and Curecanti Creek (spring).

Nutrients

Nitrogen concentrations were low in the stream inflows to Morrow Point Reservoir. Concentrations of total nitrogen in the inflows were from 0.07 to 0.5 mg/L (table 37). Much of the total nitrogen was organic nitrogen. Inorganic nitrogen concentrations in the inflows ranged from less than 0.005 to 0.14 mg/L (table 37). The dominant form of inorganic nitrogen varied between ammonia and nitrate for all sampling periods except early winter when nitrate was dominant. All nitrate, nitrite, and un-ionized ammonia concentrations in the inflows were much lower than Colorado instream water-quality standards (table 6).

Total phosphorus concentrations ranged from 0.04 to 0.14 mg/L (table 37). Elevated concentrations (above 0.1 mg/L) were detected in Pine Creek. Beaver complexes and livestock grazing are both present upstream from the Pine Creek sampling site, and decomposing organic matter may have contributed to the elevated total phosphorus concentrations. Concentrations of total phosphorus in all samples for Curecanti, Blue, and Pine Creeks were above the recommended limit of 0.05 mg/L to control eutrophication in water bodies (U.S. Environmental Protection Agency, 1986). Only Corral Creek had total phosphorus concentrations less than 0.05 mg/L. During spring when streamflow and suspended-sediment concentrations were high, over

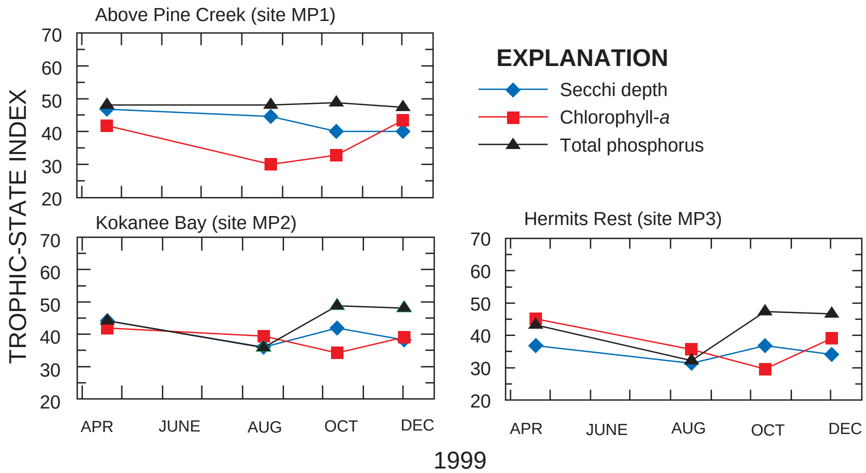

Figure 19. Trophic-state indices for Morrow Point Reservoir, calculated from Secchi depth, chlorophyll-*a*, and total phosphorus, April–December 1999.

50 percent of the total phosphorus in the four inflows was particulate phosphorus. Dissolved phosphorus was prominent in the inflows during the other three sampling periods. Most of the dissolved phosphorus was orthophosphate, which ranged in concentration from 0.016 to 0.094 mg/L (table 37).

Characteristics of Reservoir Outflow

Two sources were used for information on the outflow from Morrow Point Reservoir. Data on the amount of water released from the reservoir were obtained from the Bureau of Reclamation (1999b, 2000), whereas physical properties and water-quality data were collected on the Gunnison River about 0.25 mile downstream from Morrow Point Dam at the inflow to Crystal Reservoir (site MO, table 1, fig. 1).

Outflow from Morrow Point Reservoir ranged from 1,109 to 3,196 ft^3/s for the four sampling periods (table 36). Outflow mirrored inflow (fig. 3). The outflow tended to vary depending on power generation needs. Water temperatures in the outflow from Morrow Point Reservoir ranged from 6.0° to 11.2°C and reflected cold hypolimnetic releases. Dissolved-oxygen concentrations and pH met Colorado instream water-quality standards (table 6). Specific conductance varied little in the outflow, ranging from 172 to 182 µS/cm.

Total nitrogen concentrations in the outflow from Morrow Point Reservoir ranged from 0.1 to 0.3 mg/L (table 37). Inorganic nitrogen concentrations were low, ranging from 0.01 mg/L during May to 0.07 mg/L during August. Almost one-third or greater of the inorganic nitrogen during May and August was ammonia, whereas over 90 percent of the October and December inorganic nitrogen was nitrate. Total phosphorus concentrations were low in the outflow, ranging from 0.019 mg/L during December to 0.034 mg/L during May (table 37). Orthophosphate concentrations were consistently low in the outflow, from 0.006 mg/L during May to 0.015 mg/L during October.

Table 15. Percentage of total inflow into Morrow Point Reservoir for each sampled inflow site, May–December 1999

[Site number refers to table 1 and figure 1; columns may not add to 100 because of rounding; <, less than]

Inflow site	Percentage of total reservoir inflow			
	May/June	August	October	December
Blue Mesa Reservoir discharge (site BO)	85	96	99	97
Corral Creek (site MI2)	0.27	0.01	<0.01	0.03
Curecanti Creek (site MI3)	7.5	0.63	0.18	0.45
Pine Creek (site MI4)	0.29	0.06	0.05	0.26
Blue Creek (site MI5)	6.9	3.1	0.73	2.1

LIMNOLOGY OF CRYSTAL RESERVOIR

Reservoir data discussed in this section are located in tables 26, 28, and 38–40 of the “Supplemental Data” section at the back of this report.

Physical Properties

Water temperature in Crystal Reservoir at the site near Crystal Dam ranged from 15.5°C at the 1- to 3-m depth during August to 4.3°C at depth during April (fig. 20, table 38). Cold-water releases from Morrow Point Reservoir and reservoir topography of steep canyon walls contributed to the cold water temperatures. Crystal Reservoir was stratified during August and isothermal for the other three sampling periods (fig. 20). Two thermal discontinuities were present during summer stratification, in the metalimnion and hypolimnion. Isothermal conditions in Crystal Reservoir during October were in contrast to the October stratification in the two upstream reservoirs. The drawdown of Crystal Reservoir on September 17 may have caused a breakdown in stratification, resulting in isothermal conditions during October.

Dissolved-oxygen concentrations at the site near Crystal Dam ranged from 10.3 mg/L during April, when water temperatures were coldest, to 3.2 mg/L at depth during October (fig. 20, table 38). Anoxic conditions did not exist. Dissolved-oxygen concentrations in Crystal Reservoir were mostly uniform with depth during mixing conditions in April, October, and December, although a significant decrease from 7.0 to 3.2 mg/L did occur near the bottom of the water column during October. During August stratification, dissolved-oxygen concentrations were mostly uniform with depth until the lowest one-third of the hypolimnion where concentrations decreased in the area of the secondary thermal discontinuity. All dissolved-oxygen concentrations in the epilimnion and metalimnion met the Colorado water-quality standard (table 6).

In Crystal Reservoir, pH ranged from 7.2 to 8.4 standard units (fig. 20, table 38). Throughout the water column, pH was higher during April and August than during October and December. During isothermal or mixing conditions, pH was mostly uniform with depth or varied only by a few tenths of a unit. The pH distribution during summer reflected thermal stratifications, with decreases in the metalimnion and lowest one-third of the hypolimnion. All pH values were within the Colorado water-quality standard (table 6). There was no correlation between pH values and chlorophyll-*a* concentrations, as measured by the rank Kendall correlation coefficient at a significance level of $p \leq 0.05$. Values of pH in Crystal Reservoir were similar to those detected in Blue Mesa and Morrow Point Reservoirs.

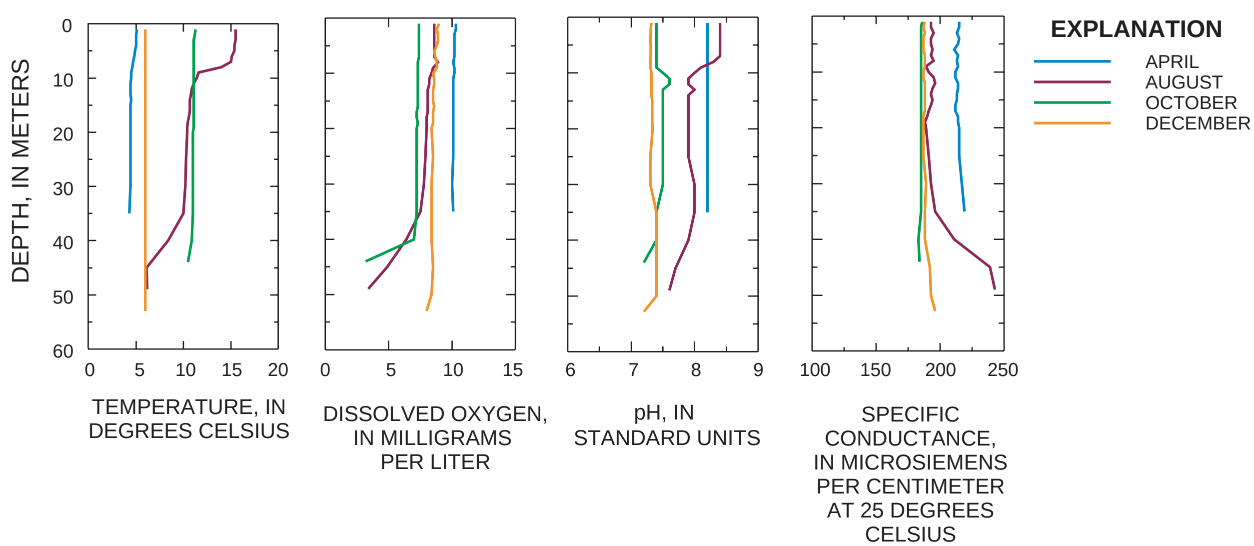

Figure 20. Depth profiles of water temperature, dissolved oxygen, pH, and specific conductance, Crystal Reservoir near Crystal Dam (site CR1), April–December 1999.

Specific conductance in Crystal Reservoir ranged from 183 to 243 µS/cm (fig. 20, table 38), indicating dissolved-solids concentrations of about 110 to 146 mg/L (conversion factor of 0.6; Hem, 1985). Specific conductance was higher during spring and summer than later in the year. During isothermal conditions, specific conductance was mostly uniform with depth. With stratification during August, specific conductance increased sharply in the deepest 20 m of the reservoir; this increase was unique among all Curecanti NRA reservoir sites. The increase in Crystal Reservoir was located in the area of the hypolimnion secondary thermal discontinuity and may be the result of water of high specific conductance in the reservoir's main stream inflow, the Cimarron River, flowing along the bottom of the reservoir. Specific conductance in Crystal Reservoir was higher than that in Blue Mesa or Morrow Point Reservoirs.

Light transparency in Crystal Reservoir ranged from 3.0 to 5.5 m for the spring through fall sampling periods (fig. 21, table 38)) and averaged 4.0 m. The early winter Secchi depth was not recorded. Transparency was at a minimum during spring and at a maximum during summer. With the photic zone estimated as three times the Secchi depth, the photic zone at the Crystal Reservoir site ranged between 9.0 and 16.5 m.

Nutrients

Total nitrogen concentrations in Crystal Reservoir at the site near Crystal Dam ranged from 0.1 to 0.4 mg/L (fig. 22, table 39). Most nitrogen in Crystal Reservoir was organic nitrogen. Concentrations of dissolved inorganic nitrogen in the reservoir ranged from 0.009 to 0.19 mg/L (fig. 22, table 39). Only the summer samples from the epilimnion had concentrations less than or equal to 0.010 mg/L. All other samples had concentrations greater than or equal to 0.039 mg/L. Much of the dissolved inorganic nitrogen in the photic zone during spring, fall, and early winter occurred as nitrate. Nitrate was undetected in the epilimnion during summer, and more of the dissolved inorganic nitrogen occurred as ammonia. In Crystal Reservoir, maximum concentrations for both total nitrogen and dissolved inorganic nitrogen occurred at depth during summer stratification and were much greater than the corresponding epilmnion concentrations. All nitrate, nitrite, and un-ionized ammonia concentrations in the reservoir were well within the Colorado water-quality standards (table 6). Concentrations of total nitrogen in Crystal Reservoir were similar to those detected in Blue Mesa and Morrow Point Reservoirs, whereas concentrations of dissolved inorganic nitrogen in Crystal Reservoir were higher than those in the two upstream reservoirs.

Total phosphorus concentrations in Crystal Reservoir were low, ranging between 0.009 and 0.057 mg/L (fig. 22, table 39). The only concentration greater than 0.023 mg/L was in the summer bottom-water sample during stratification. Dissolved orthophosphate concentrations in the reservoir also were low, ranging from less than the reporting level of 0.001 to 0.02 mg/L (fig. 22, table 39). Concentrations below the laboratory reporting level only were in the summer epilimnion samples. Spring, fall, and early winter concentrations of both total phosphorus and dissolved orthophosphate were mostly uniform with depth and reflected the unstratified conditions in the water column. With stratification, concentrations were higher in the hypolimnion than in other parts of the water column.

Phosphorus was the limiting nutrient in Crystal Reservoir during spring, whereas nitrogen was the limiting nutrient during fall and early winter (table 12). During summer, phosphorus probably was the limiting nutrient because inorganic nitrogen concentrations were 0.009 or 0.010 mg/L and orthophosphate concentrations were less than the reporting limit of 0.001 mg/L.

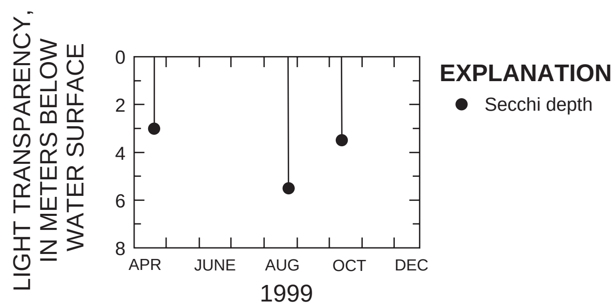

Figure 21. Light transparency in Crystal Reservoir near Crystal Dam (site CR1), April–December 1999.

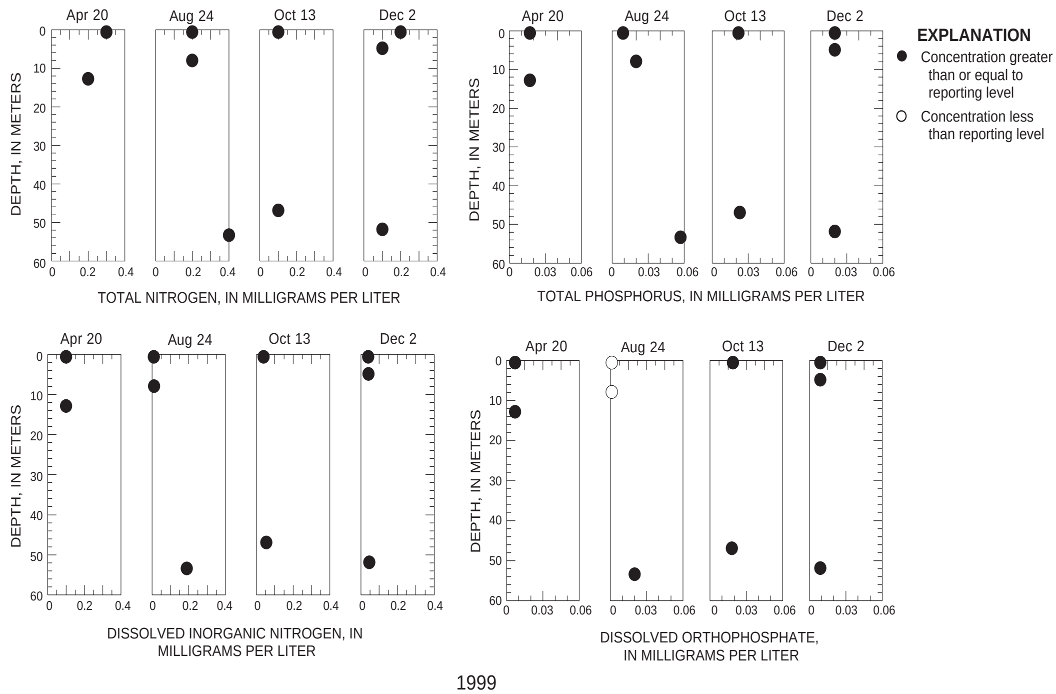

Figure 22. Nitrogen and phosphorus concentrations in Crystal Reservoir near Crystal Dam (site CR1), April–December 1999.

Phytoplankton

Phytoplankton density in Crystal Reservoir was nearly constant for the April, October, and December samples, when densities ranged from 175 to 183 algal units/L, and reached a maximum level of 393 algal units/L during August (fig. 23, table 40). Genera richness in the reservoir was greatest during summer and lowest during early winter (fig. 24).

The pattern of phytoplankton density in Crystal Reservoir (fig. 23) differed from that in Blue Mesa (fig. 7) and Morrow Point Reservoirs (fig. 15). Both Blue Mesa and Morrow Point Reservoirs had minimum phytoplankton density during August, whereas Crystal Reservoir had maximum phytoplankton density during August. Algal density in Crystal Reservoir, from 175 to 393 algal units/L, was much smaller and much less variable than that in Blue Mesa and Morrow Point Reservoirs, which had densities of 26 to 21,930 algal units/L and 19 to 1,264 algal units/L, respectively. These differences in density among the three reservoirs may be related to residence time, water temperature, and nutrients. The first two factors, in particular, decreased along an upstream-to-downstream gradient among the reservoirs.

The phytoplankton community in Crystal Reservoir in 1999 was dominated by diatoms (figs. 25–26). Diatoms made up about 98, 85, and 95 percent of the phytoplankton community during spring, summer, and fall, respectively, and were the only phytoplankton detected during early winter. *Melosira* sp. was the dominant diatom genera in all samples except summer, when *Asterionella* sp. was dominant. Other phytoplankton present in small amounts during spring, summer, and(or) fall were the golden-brown algae *Dinobryon* sp., the green algae *Schroederia* sp., the dinoflagellate *Ceratium* sp., and the blue-green algae *Aphanizomenon* sp.

Historical phytoplankton data for this site, which are available only for fall 1998, revealed the presence of five diatom genera *(Melosira*, *Fragilaria*, *Stephanodiscus*, *Synedra*, and *Navicula*), four green algae genera (*Gloeocystis*, *Eudorina*, *Closteridium*, and *Oedogonium*), and the dinoflagellate *Ceratium* (National Park Service, 1998b). The first two diatoms and *Ceratium* were the only phytoplankton in common for fall 1998 and fall 1999.

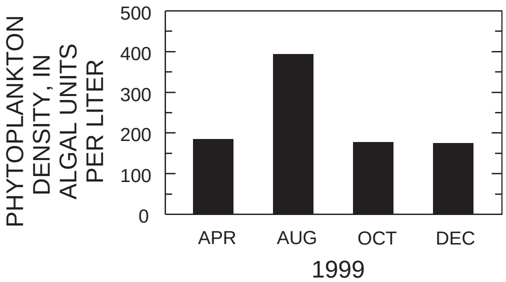

Figure 23. Phytoplankton density in Crystal Reservoir near Crystal Dam (site CR1), April–December 1999.

Chlorophyll-*a*

Chlorophyll-*a* concentrations near Crystal Dam ranged from 2.01 to 3.32 mg/m^3 (table 28). The mean concentration of 2.64 mg/m^3 would indicate oligotrophy (Likens, 1975). Chlorophyll-*a* concentrations in Crystal Reservoir were at a minimum during August and at a maximum during December. No correlation existed between chlorophyll-*a* concentration and phytoplankton density. TSI values ranged from 36 to 49 for total phosphorus, 37 to 42 for chlorophyll-*a*, and 35 to 44 for Secchi depth (fig. 27, table 28). Indices for all three parameters were very similar during spring and summer and tended to diverge slightly during fall.

Characteristics of Reservoir Inflows

Data discussed in this section are located in tables 41–42 of the "Supplemental Data" section at the back of this report.

Physical Properties and Suspended Sediment

Four inflow sources were investigated for Crystal Reservoir: the outflow from Morrow Point Reservoir (site MO) (discussed above in "Characteristics of Reservoir Outflow" for Morrow Point Reservoir) and the stream inflows Cimarron River and Mesa and Crystal Creeks (sites CI4, CI2, and CI3, respectively) (fig. 1, table 1). Most (median of 97 percent) of the water flowing into Crystal Reservoir during the four sampling periods was outflow from Morrow Point Reservoir. The remainder was mainly supplied by the Cimarron River (table 16). Discharge in the three stream tributaries ranged from 0.11 to 194 ft^3/s, and except during spring snowmelt, streamflow in Crystal and Mesa Creeks was less than 1 ft^3/s (table 41).

Water temperature in the inflows to Crystal Reservoir ranged from 0.0° to 16.8°C, and the median was 8.4°C (table 41). Temperatures reflected a seasonal cycle, with the warmest water generally during August, followed by cooler water during May/June and October, and the coolest water during December. Crystal Creek was the exception to this, as its warmest water was in May.

The stream inflows to Crystal Reservoir generally were well oxygenated (table 41). Most dissolved-oxygen concentrations for all four sampling periods were at or near 100-percent saturation, indicating good conditions for aquatic organisms. The exception to high saturation values was Crystal Creek during October with 72-percent saturation. Dissolved-oxygen concentrations in each inflow met the Colorado aquatic-life instream standard (table 6).

The median pH in the Crystal Reservoir inflows was 8.2 (table 41). There was little possibility of un-ionized ammonia toxicity to fish at these pH values because all dissolved ammonia concentrations were at or below 0.01 mg/L. All pH values were within the Colorado instream standard (table 6). The median pH in the inflows to Crystal Reservoir was higher than that detected in inflows to Blue Mesa and Morrow Point Reservoirs.

Specific conductance in the three inflows to Crystal Reservoir ranged from 48 to 449 µS/cm (table 41). Both Cimarron River and Crystal Creek had high values of specific conductance; median specific-conductance values for these two inflows were 402 and 418 µS/cm, respectively. Both inflows drain agricultural lands that include deposits of Mancos Shale, a highly erodible Upper Cretaceous

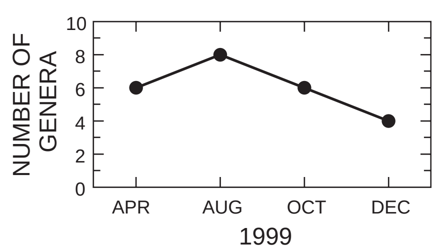

Figure 24. Genera richness in Crystal Reservoir near Crystal Dam (site CR1), April–December 1999.

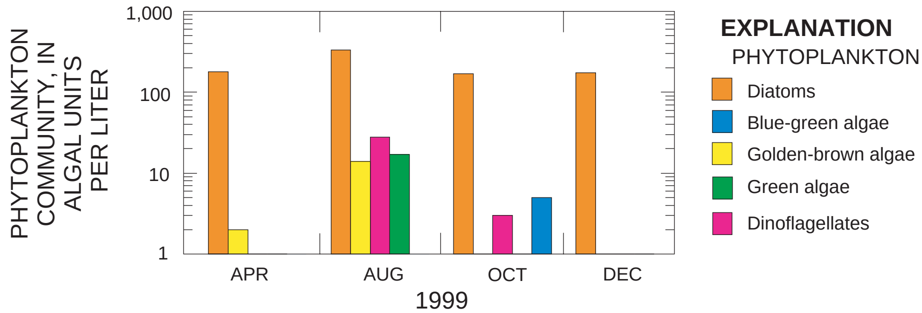

Figure 25. Phytoplankton community in Crystal Reservoir near Crystal Dam (site CR1), April–December 1999.

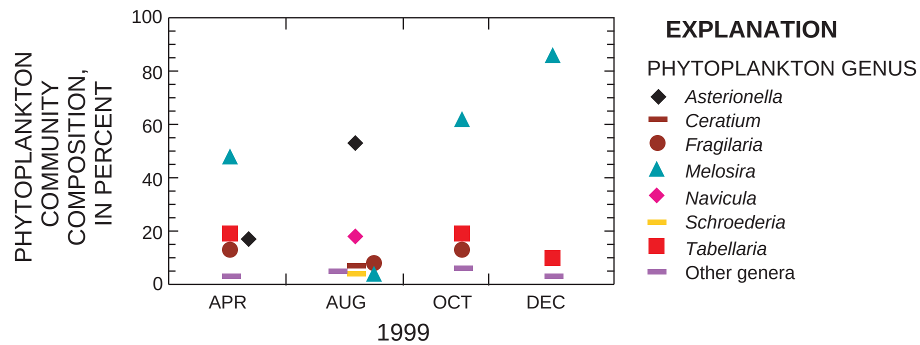

Figure 26. Percent composition of phytoplankton community by genera, Crystal Reservoir near Crystal Dam (site CR1), April–December 1999.

saline, marine sedimentary rock. Crystal Creek is subject to water withdrawals for irrigation and may be dry at certain times of the year. The Cimarron River has substantial streamflow throughout the year and, therefore, has a larger effect on the quality of water in Crystal Reservoir than does Crystal Creek. In Crystal Reservoir, there was a substantial increase in specific conductance, about 50 µS/cm, in the lower hypolimnion during stratification in August. More dense water from the Cimarron River may sink to the reservoir bottom and cause the high specific conductance at depth. Sampling along the length of the reservoir would be needed to verify this. Specific conductance in the inflows to Crystal Reservoir was higher than that in most inflows to Blue Mesa and Morrow Point Reservoirs.

Suspended-sediment concentrations in the three Crystal Reservoir inflows ranged from 1 to 133 mg/L (table 41). Suspended sediment is not a water-quality concern in Mesa and Crystal Creeks but is a concern in the Cimarron River. The median suspended-sediment concentration in the river was 36 mg/L, and concentrations especially were elevated during June and August. The June concentration of 133 mg/L was highest among all reservoir inflows in Curecanti NRA. A sediment plume could easily be seen during the spring, summer, and fall sampling periods at the point where the Cimarron River enters the Gunnison River (fig. 28), just upstream from Crystal Reservoir. As such, the Cimarron River supplied almost all of the sediment load to Crystal Reservoir for the four sampling periods.

Nutrients

Total nitrogen concentrations in the stream inflows to Crystal Reservoir ranged from 0.1 to 0.6 mg/L (table 42). Most total nitrogen in the inflows was dissolved organic nitrogen. Except for Mesa Creek and the Cimarron River during December, dissolved inorganic nitrogen accounted for less than one-third of total nitrogen. Inorganic nitrogen concentrations in the inflows were from less than 0.005 to 0.18 mg/L (table 42). Most inorganic nitrogen in Mesa

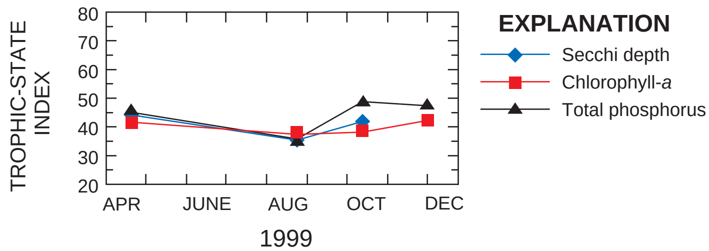

Figure 27. Trophic-state indices for Crystal Reservoir near Crystal Dam (site CR1), calculated from Secchi depth, chlorophyll-*a*, and total phosphorus, April–December 1999.

Creek and the Cimarron River was nitrate, whereas ammonia was dominant in Crystal Creek during August and October. All nitrate, nitrite, and un-ionized ammonia concentrations met Colorado instream water-quality standards (table 6). Concentrations of total nitrogen and dissolved inorganic nitrogen in the inflows to Crystal Reservoir were the highest among all inflows to the recreation area.

Total phosphorus concentrations in the three inflows ranged from 0.027 to 0.17 mg/L (table 42). Elevated concentrations (above 0.1 mg/L) were detected in the Cimarron River. At least one-half of the samples for Crystal Creek and Cimarron River had total phosphorus concentrations exceeding the recommended limit of 0.05 mg/L to control eutrophication in water bodies (U.S. Environmental Protection Agency, 1986). Most total phosphorus in Crystal Creek occurred as dissolved phosphorus, whereas the percentage of total phosphorus in Mesa Creek and the Cimarron River as either particulate or dissolved phosphorus was related to streamflow and suspended-sediment concentration. When the latter two parameters were elevated, particulate phosphorus was the primary form of total phosphorus. Most dissolved phosphorus in the inflows was orthophosphate. Orthophosphate concentrations were low, ranging from 0.011 to 0.052 mg/L (table 42).

Characteristics of Reservoir Outflow

Two sources were used for information on the outflow from Crystal Reservoir. Data on the amount of water released from the reservoir were obtained from the Bureau of Reclamation (1999b, 2000), whereas physical properties and water-quality data collected at the Gunnison River below Gunnison Tunnel site (site CO), about 2 miles downstream from Crystal Dam, were used to represent the quality of the water released from the reservoir. The major hydrologic feature between Crystal Dam and the sampling site, the Gunnison Tunnel, routed water away from the Gunnison River during the irrigation season.

The amount of water released from Crystal Reservoir ranged from 1,209 to 3,824 ft^3/s for the four sampling periods (table 41). Abrupt changes in discharge throughout the year reflected the regulation of water released from Crystal Dam (fig. 3). Water temperature in the Gunnison River below the Gunnison Tunnel ranged from 6.5° to 11.5°C, reflecting cold hypolimnetic releases from Crystal Reservoir. Dissolved-oxygen concentrations and pH were within Colorado instream standards (table 6). Specific-conductance values in the river were around 190 µS/cm. Suspended-sediment samples were not collected at the Gunnison River below Gunnison Tunnel site in 1999; however, sampling between 1994 and 1998 indicated that suspended-sediment concentrations at the site were low (median of 3 mg/L) (Spahr and others, 2000).

Table 16. Percentage of total inflow into Crystal Reservoir for each sampled inflow site, May–December 1999

[Site number refers to table 1 and figure 1; columns may not add to 100 because of rounding; <, less than]

Inflow site	Percentage of total reservoir inflow			
	May/June	August	October	December
Morrow Point Reservoir outflow (site MO)	93	96	98	98
Mesa Creek (site CI2)	1.0	0.02	<0.01	0.02
Crystal Creek (site CI3)	0.09	<0.01	<0.01	0.01
Cimarron River (site CI4)	5.7	4.3	2.4	2.3

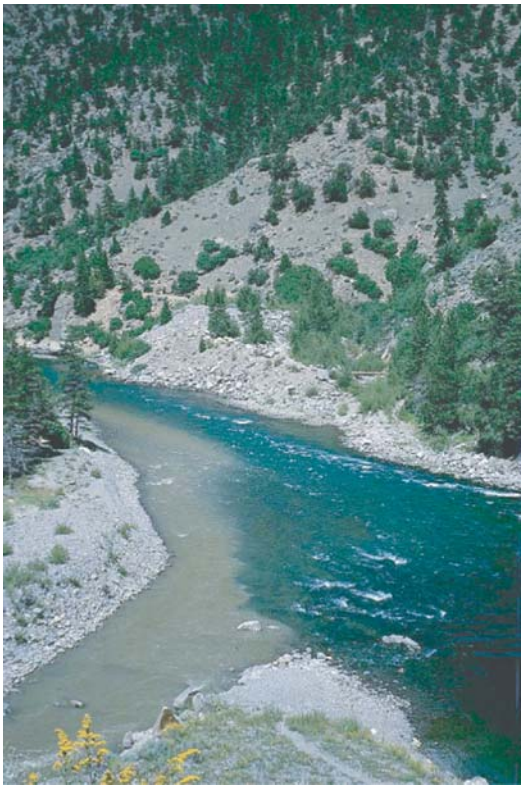

Figure 28. Mouth of Cimarron River at Gunnison River, August 1999. Photograph by Nancy Bauch.

Total nitrogen concentrations in the Gunnison River below the Gunnison Tunnel site ranged from 0.1 to 0.4 mg/L, with the maximum concentration occurring during May (table 42). Inorganic nitrogen concentrations in the river were low, ranging between 0.018 mg/L during May to 0.083 mg/L during December. Nitrate was the primary component of inorganic nitrogen, especially during August, October, and December. Total phosphorus concentrations ranged from 0.022 to 0.07 mg/L in the outflow from Crystal Reservoir (table 42) and were more variable than those from the upstream reservoirs. Orthophosphate concentrations were similar, however, to the upstream reservoir outflows and ranged from 0.007 to 0.015 mg/L.

Nutrient loads in the outflow from Crystal Reservoir were estimated using nutrient concentrations from the Gunnison River below Gunnison Tunnel site and water released from Crystal Reservoir. Mean annual loads for 1995–99 were highest for total nitrogen and lowest for dissolved orthophosphate (table 17). Nutrient loads in the Crystal Reservoir outflow were greatest in May–July, similar to those for the Gunnison River at County Road 32 site (site BI1) upstream from Blue Mesa Reservoir. For other months of the year, the amount of nutrient loading in the outflow from Crystal Reservoir was more consistent than the amount of loading in the upstream Gunnison River at County Road 32 site and reflected continual water releases from Crystal Dam rather than seasonal streamflow patterns at the upstream Gunnison River site.

COMPARISON OF RESERVOIRS, INFLOWS, AND OUTFLOWS

Physical properties, nutrients, phytoplankton, and chlorophyll-*a* for Blue Mesa, Morrow Point, and Crystal Reservoirs will be compared, as will physical properties and nutrients in stream inflows and reservoir outflows. Possible implications for management also will be discussed.

Physical Properties in Reservoirs

Blue Mesa, Morrow Point, and Crystal Reservoirs had temperature characteristics common to lakes and reservoirs in temperate latitudes. Each reservoir had isothermal conditions and vertical mixing of water during spring and early winter and thermal stratification during summer. Major differences in water temperature between the reservoirs—Blue Mesa being the warmest with the greatest range in temperature and Crystal being the coolest with smallest range in temperature—were related to the presence or absence of an impoundment in close, upstream proximity to each reservoir. The nearest major dam upstream from Blue Mesa Reservoir is Taylor Park Reservoir, 37 miles distant, and is too far removed to have an effect on temperatures in the Gunnison River as it enters Blue Mesa Reservoir. Temperatures in the Gunnison River at County Road 32, for example, ranged between 0.0° and 13.3°C for the four sampling periods. Inflow temperatures to Blue Mesa Reservoir reflected the seasonal hydrologic cycle rather than effects from upstream impoundments. By comparison, the temperature of water released from Blue Mesa and Morrow Point Dams ranged between 6.0° and 12.5°C. As a result of receiving deep outflow water from adjacent upstream impoundments, spring and early winter temperatures in Morrow Point and Crystal Reservoirs were warmer

Table 17. Estimated mean annual and monthly discharge and nutrient loads for outflow from Crystal Reservoir, calendar years 1995–99

[acre-ft/d, acre-foot per day; kg/d, kilograms per day]

Month	Mean discharge (acre-ft/d)	Mean load (kg/d)			
		Total nitrogen	Dissolved inorganic nitrogen	Total phosphorus	Dissolved orthophosphate
January	2,339	550	270	63	38
February	2,195	510	230	57	36
March	3,066	780	310	100	50
April	4,077	1,100	390	140	66
May	6,183	1,800	580	270	100
June	6,844	2,000	640	330	120
July	7,170	2,200	720	380	130
August	4,370	1,200	370	160	70
September	3,639	920	320	120	58
October	3,444	870	340	110	55
November	2,775	670	300	80	45
December	2,813	690	320	82	45
Annual	4,076	1,100	400	160	68

than would have occurred without the upstream impoundment, and summer temperatures were cooler. Water temperature in Morrow and Crystal Reservoir also was affected by the reservoirs' location in the Black Canyon of the Gunnison River. The steep sides and narrowness of the canyon limit the amount of solar radiation absorbed by each reservoir.

Thermal stratification was present at each reservoir site during summer, except for Morrow Point Reservoir Above Pine Creek. Stratification continued into fall for Blue Mesa Reservoir at Cebolla and Sapinero Basins and in Morrow Point Reservoir at Kokanee Bay and Hermits Rest. A secondary thermal discontinuity was present during summer at Hermits Rest and in Crystal Reservoir at the site near Crystal Dam.

Dissolved-oxygen concentrations in each reservoir were inversely related to water temperature, with the highest median photic-zone concentration occurring in the cooler Crystal Reservoir and the lowest median photic-zone concentration occurring in the warmer Blue Mesa Reservoir. In Blue Mesa Reservoir, decreases in dissolved-oxygen concentration were in the metalimnion of Cebolla and Sapinero Basins during August and October stratification. For both basins, dissolved-oxygen concentrations were at a minimum in the metalimnion 40 m below the water surface during August, with an additional minimum at 19 m in Sapinero Basin, and between 35 and 50 m below the water surface during October. The deeper metalimnetic oxygen minimums may be related to the power-gate slot openings on Blue Mesa Dam, as the dissolved-oxygen minimums during August were situated just above the power-gate slot openings, and the fall minimums were within the power-gate slot openings. As noted by Ford (1990), because stratification in a reservoir prevents vertical mixing, the zone of outflow or water removal may extend the length of the reservoir. This outflow zone may be reflected by the dissolved-oxygen minimums in Cebolla and Sapinero Basins of Blue Mesa Reservoir. The metalimnetic minimums during October also may be related to phytoplankton decomposition. As dead phytoplankton fall from the epilimnion, they can accumulate in the metalimnion because the cooler, more dense water found there slows the rate of sinking through the water column. The amount of oxygen depletion through bacterial respiration is greatest in the metalimnion because of the longer period of time the sinking phytoplankton spend in this region of higher viscosity, leading to a metalimnetic oxygen minimum. This mechanism for metalimnetic oxygen depletion has been observed in another Colorado River reservoir, Lake Powell in Utah (Stanford and Ward, 1991). The metalimnetic dissolved-oxygen minimum observed in Blue Mesa Reservoir in 1999 also was detected in previous years (Johnson and Bergstedt, 1994; Johnson and others, 1995, 1996, 1997). The exact mechanism of the metalimnetic dissolved-oxygen minimum in Blue Mesa Reservoir is unknown.

Nutrients in Reservoirs

Similarities and differences in nutrient concentrations in the three reservoirs were observed, as shown by seasonal median concentrations in the epilimnion/photic zone and hypolimnion (near bottom) for each reservoir (fig. 29). Except for the summer near-bottom sample from Crystal Resevoir, seasonal median concentrations of total nitrogen in Morrow Point and Crystal Reservoirs were less than or equal to those in Blue Mesa Reservoir. Some median concentrations of total nitrogen were higher at depth during stratified conditions and probably were due to the settling of organic detritus from above. The high median concentration at depth in Crystal Reservoir during summer also may have resulted from dense Cimarron River water sinking to the bottom of the reservoir. For inorganic nitrogen, seasonal median concentrations in photic-zone and near-bottom samples were nearly similar within each reservoir during mixing conditions (fig. 29). In Blue Mesa and Morrow Point Reservoirs, median inorganic nitrogen concentrations in epilimnion samples were less than the reporting limit of 0.005 mg/L during summer, indicating full utilization by biota. Inorganic nitrogen was not fully utilized in Crystal Reservoir during summer, reflecting the possibility that phosphorus may have been the limiting factor. Excluding some Blue Mesa Reservoir samples during stratification, median inorganic nitrogen concentrations at the different depths were higher in Morrow Point and Crystal Reservoirs than in Blue Mesa Reservoir for each sampling period. Median total phosphorus concentrations in the three reservoirs were similar or nearly similar except during stratification (fig. 29). Results for dissolved orthophosphate were mostly similar to results for dissolved inorganic nitrogen. Median orthophosphate concentrations during summer, though, were less than the reporting limit in Blue Mesa and Crystal Reservoirs.

In each reservoir, the limiting nutrient during spring was phosphorus and the limiting nutrient during early winter was nitrogen. In Blue Mesa and Morrow Point Reservoirs, nitrogen was probably the limiting nutrient during summer for some sites, whereas for other sites the limiting nutrient during summer could not be determined because both inorganic nitrogen and orthophosphate concentrations were less than laboratory reporting levels. Phosphorus probably was the limiting nutrient in Crystal Reservoir during summer. During fall, nitrogen was limiting in Morrow Point and Crystal Reservoirs and probably was the limiting nutrient in Blue Mesa Reservoir.

Phytoplankton in Reservoirs

The size and structure of the phytoplankton community in each reservoir fluctuated throughout the sampling period due to physical, chemical, and biological factors. These include water residence time, water temperature, sunlight, thermal stratification, nutrients, and characteristics of phytoplankton species. In particular, the phytoplankton communities in Morrow Point and Crystal Reservoirs were affected more by water residence time and water temperature than in Blue Mesa Reservoir. Phytoplankton density generally was less in Morrow Point and Crystal Reservoirs than in Blue Mesa Reservoir, and residence times were in weeks and days for Morrow Point and Crystal Reservoirs, respectively, and in months for Blue Mesa Reservoir. Water residence time has been shown to strongly influence phytoplankton abundance, as algal abundance increases with residence time (Soballe and Kimmel, 1987). The short residence times in Morrow Point and Crystal Reservoirs could limit the time phytoplankton had to reproduce and, thus, could limit the population size. Phytoplankton growth and development in these two reservoirs also could have been limited by lower water temperatures. Most of the water supplied to Morrow Point and Crystal Reservoirs was from cold, deep discharges from the upstream impoundment. Temperatures in Morrow Point and Crystal Reservoirs usually were less than those in Blue Mesa Reservoir because of the short residence times and the lack of solar radiation to warm the cold, deep-discharge inflow waters.

As with other lakes or reservoirs in temperate latitudes, there were general patterns in the composition of phytoplankton communities in the three Curecanti NRA reservoirs. In oligotrophic Morrow Point and Crystal Reservoirs, most of the phytoplankton biomass was supplied by diatoms. Blue-green algae accounted for only a small amount of the phytoplankton biomass

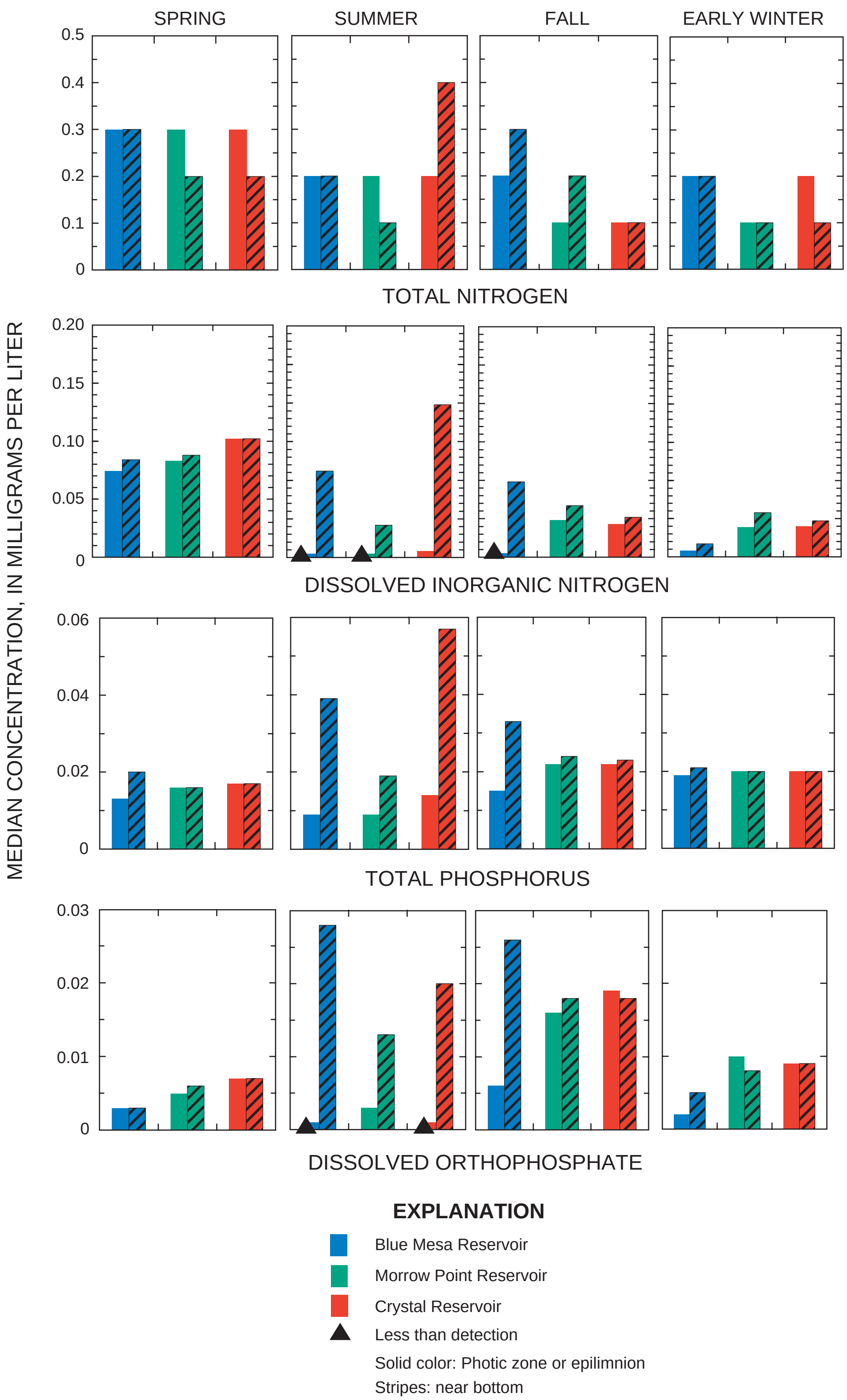

Figure 29. Median nutrient concentrations in Curecanti National Recreation Area, April–December 1999.

in these reservoirs with lower productivity. This pattern is typical of lakes and reservoirs in temperature latitudes of the Northern Hemisphere (Watson and others, 1997). In the more nutrient-rich Blue Mesa Reservoir, especially Iola Basin, blue-green algae replaced diatoms as the dominant phytoplankton during August and October. Green algae never were the primary phytoplankton group in any of the three reservoirs. The amount of green algae generally is small in north temperate-latitude lakes or reservoirs because the rate of increase in green algae biomass with increasing total phosphorus is much slower than diatoms or blue-green algae (Watson and others, 1997). The dinoflagellate *Ceratium* sp. was present in the reservoirs at certain times in small amounts. Even though *Ceratium* sp. can regulate their position in the water column to that which is favorable for nutrients and sunlight, dinoflagellates, in general, are only a small part of the phytoplankton biomass in lakes or reservoirs of north temperate latitudes.

Patterns in community composition with respect to individual genera depended partly on characteristics of the particular phytoplankton. In each reservoir, diatoms were dominant during April, and *Melosira* sp. and *Asterionella* sp. were the primary genera. Among diatoms, *Melosira* sp. are characterized as a winter-spring species, as they survive in a resting stage in reservoir sediment during nonbloom periods and are resuspended from the sediment during spring turnover (Horne and Goldman, 1994). This mechanism would account for the early season presence of *Melosira* sp. in the Curecanti NRA reservoirs. During spring, diatoms are able to grow faster and thus outcompete other algae, and *Asterionella* sp. grows the fastest among the diatoms. In many lakes and reservoirs, *Melosira* sp. are at a maximum before the spring dominance of *Asterionella* sp. (Horne and Goldman, 1994). Because *Melosira* sp. are heavy diatoms with thick silica walls, they require mixing conditions to be resuspended from sediment and to remain in the water column. Once stratification begins, *Melosira* sp. sink and again reside in the sediment.

Factors that eventually limit the growth of diatoms into the summer are the depletion of nutrients in the epilimnion, water temperature, grazing by zooplankton, and parasitism. Limiting nutrients may be nitrogen, phosphorus, and silica, the latter used for cell walls. Phytoplankton populations in Blue Mesa Reservoir (mainly blue-green algae and diatoms) and Morrow Point Reservoir (mainly diatoms) were at a minimum during August when inorganic nitrogen concentrations in most surface water were below detection and essentially fully depleted by biological activities. In contrast, the Crystal Reservoir phytoplankton population, primarily diatoms, was at a maximum during August. Inorganic nitrogen was not fully utilized, and phosphorus was probably the limiting nutrient.

During October, the bloom of blue-green algae *Aphanizomenon* sp. occurred in Blue Mesa Reservoir because inorganic nitrogen concentrations in surface waters were again below detection and higher water temperatures prevailed. *Aphanizomenon* sp. can fix atmospheric nitrogen for use as a food source when inorganic nitrogen in a water body is extinguished. *Aphanizomenon* sp. thrive in warm water and reproduce faster than diatoms in higher water temperatures (Horne and Goldman, 1994). Additionally, blue-green algae can regulate their position in the water column to take maximum advantage of environmental conditions.

Diatoms were dominant in Morrow and Crystal Reservoirs during October because inorganic nitrogen (median of 0.054 mg/L) was available in surface water, and cooler water temperatures were present. Straskraba and Budejovice (1990) reported similar results for a downstream reservoir receiving hypolimnetic releases from an upstream reservoir: a shift in phytoplankton composition from eutrophic assemblages with blooms of blue-green algae toward oligotrophic assemblages with more diatoms, and a decrease in primary productivity. Primary productivity in Morrow Point and Crystal Reservoirs, as reflected by median chlorophyll-*a* concentrations at each site, was significantly ($p<0.04$) lower than in Blue Mesa Reservoir. With fall turnover and the end of stratification in each reservoir, *Melosira* sp. became the primary diatom.

Chlorophyll-*a* in Reservoirs

Mean chlorophyll-*a* concentrations in the three reservoirs were highest in the most upstream area of the recreation area. The highest mean chlorophyll-*a* concentrations were detected in Blue Mesa Reservoir, the most upstream reservoir, and in Iola and Cebolla Basins, the most upstream basins in the Blue Mesa Reservoir. Using mean chlorophyll-*a* concentrations and Likens' (1975) classification system, Blue Mesa

Reservoir was mesotrophic and Morrow Point and Crystal Reservoirs were oligotrophic. TSI values for total phosphorus, chlorophyll-*a*, and Secchi depth ranged between 29 and 55. For the first two indices, only Iola and Cebolla Basins had values of 50 or greater, reflecting the higher trophic states in the basins.

Characteristics of Reservoir Inflows and Outflows

Inflow to Blue Mesa Reservoir was based on a seasonal cycle, whereas most inflow to Morrow Point and Crystal Reservoirs depended largely on operations at each upstream impoundment since most flow into these reservoirs was outflow from the respective upstream impoundment. Water temperature in the stream inflows for each reservoir reflected a seasonal cycle; the warmest temperatures generally were during August, and the coolest temperatures were during November/December. Water temperatures in the outflow from Blue Mesa and Morrow Point Reservoirs were warmest during October, followed by August, May/June, and December (the coolest). Minimum and maximum temperatures in the outflow were moderated when compared to minimum and maximum temperatures in the stream inflows. Dissolved-oxygen concentrations in the inflows were favorable for aquatic organisms, and toxicity of un-ionized ammonia to fish was not indicated. All dissolved oxygen, pH, and nitrogen values in the inflows and outflows were within water-quality standards for the State of Colorado (table 6). Total phosphorus concentrations were elevated (above 0.05 mg/L) in many of the inflows to the three reservoirs. Most elevated concentrations, however, were detected in smaller inflows that contributed little water to the reservoirs, and the resulting small total phosphorus loads in these inflows would not be a water-quality concern. Only one outflow sample, Gunnison River below Gunnison Tunnel for August, had a total phosphorus concentration above 0.05 mg/L.

Most nutrient loading into Blue Mesa Reservoir, represented by Gunnison River at County Road 32, occurred during spring snowmelt (table 14). Nutrient loading into Morrow Point and Crystal Reservoirs depended largely on operations of each upstream impoundment. Using estimated nutrient loads in outflow from Crystal Dam as a proxy for nutrient loads in outflow from Blue Mesa and Morrow Point Dams, nutrient loads into Morrow Point and Crystal Reservoirs were moderated when compared to seasonal inflow loads that would occur with the absence of the upstream impoundment(s). Nutrient loads into these two downstream reservoirs were smaller during spring snowmelt than would be expected with seasonal inflows and were higher during the rest of the year. Limnological studies of other reservoir systems have indicated that nutrient availability for phytoplankton production may increase or decrease in reservoirs downstream from deep-discharge impoundments (Elser and Kimmel, 1985). It appears that Blue Mesa Reservoir acts somewhat as a sink for phosphorus, as phosphorus concentrations in most inflows were higher than concentrations in the outflow. For Morrow Point and Crystal Reservoirs, it appears that the upstream dam discharges increased the availability of total nitrogen and dissolved inorganic nitrogen during summer, fall, and early winter. Phosphorus concentrations generally were similar in the inflows and outflows for both Morrow Point and Crystal Reservoirs.

Implications for Management

With water temperature and residence time appearing to affect productivity of the reservoirs and nutrient inflow to Morrow Point and Crystal Reservoirs affected by conditions in the upstream reservoir, the question arises as to how a change in current reservoir operations will affect productivity in all three reservoirs in terms of water temperature, residence time, and nutrient inflows. Johnson and others (1997) reported that the thermal structure in Blue Mesa Reservoir appears to be insensitive to operation changes under normal climatic conditions and that reservoir managers have much leeway in different operations without affecting kokanee salmon growth. However, effects of operation changes on nutrient dynamics were not studied. Reservoir operations can affect reservoir productivity in a variety of ways, including changes in nutrient loading and recycling, water-temperature changes, alterations in productivity levels with different temperatures, changes in the volume of stratification layers, and changes in density of organisms in each layer (Johnson and others, 1997). For the Aspinall Unit, it cannot be predicted how reservoir productivity will change under different operational schemes because it is not known how much each particular effect—for example, a change in nutrient dynamics—affects productivity. This would require a nutrient modeling study. Use of Carlson's TSI, though, can give some qualitative ideas on how various changes in total phosphorus, chlorophyll-*a*, and Secchi depth may or may not affect algal biomass.

Analysis and interpretation of data collected during this study and historical data highlighted several issues concerning sample collection. As discussed previously, there is a lack of nutrient and(or) streamflow data for most inflows and outflows that are needed for determining loads and conducting trend analysis. This 1999 study is one of the few studies where most inflows and outflows have been sampled; these samples indicated elevated total phosphorus concentrations in many inflows and fairly consistent nutrient concentrations in the reservoir outflows for the four sampling periods. Many of the smaller inflows, however, contribute little to the reservoirs, especially when compared to the largest tributaries and dam releases, and may only need to be sampled occasionally. To get an accurate estimate of nutrient loads and the movement of nutrients through the reservoir system, however, the outflows need to be sampled more frequently than seasonally. Ideally, the samples should be collected as near to the dam as possible, with no major inflows between the dam and the sampling site, rather than farther downstream. Also, streamflow should be measured at the larger inflows whenever being sampled. Little to no historical information is available on silica concentrations in the reservoirs or inflows and outflows. Because silica is an important nutrient for diatoms and can be a large component of cellular walls, it would be beneficial to have temporal and spatial information on silica concentrations in the recreation area.

RETROSPECTIVE OF NUTRIENT CONDITIONS IN BLUE MESA RESERVOIR

To assess whether water quality in Blue Mesa Reservoir has changed over time, data collected for this study during 1999 were compared to historical reservoir data for 1975, 1983, 1984, 1985, and 1998 (tables 18 and 19). Data that were compared included physical properties (pH, specific conductance, and Secchi depth collected just below the water surface), nutrients, phytoplankton, and chlorophyll-*a*. Testing for temporal trends was conducted for the sites and data listed in table 7. To reduce seasonality in the data comparisons and trend testing, data for the same months or seasons were compared; for example, August to August and late September to early October for the different years. Trends were examined with the seasonal Kendall test. Cebolla Basin is excluded from the comparisons and trend testing of annual data for physical properties and nutrients because the basin was not sampled at a consistent location over time. Phytoplankton and chlorophyll-*a* data for this site for 1975 and 1983–85 are included in the following discussion. Stream inflow sites that were examined were Gunnison River at County Road 32 and Lake Fork of the Gunnison River. Only the most important results for comparisons and trends testing are presented here.

Physical Properties

Values of pH in Iola Basin generally were lower during August and September in the mid-1980's when compared to data for 1975 and 1999 (table 18); however, no statistically significant ($p \leq 0.05$) trend in pH was detected for Iola Basin for 1984–99 (table 20). Values of pH in Sapinero Basin in the mid-1980's were slightly lower or equal to pH values for 1975 and 1999 (table 18). A statistically significant upward trend in pH was indicated for 1992–99 (table 20). In a water body, pH varies because of chemical and biological factors, especially the distribution of carbon dioxide in the water column (Wetzel, 1983). During photosynthesis, carbon dioxide is utilized as an energy source, reducing carbon concentrations and increasing pH. Greater carbon dioxide use and, thus, higher values of pH would be expected with increased algal density. Phytoplankton density was elevated in Blue Mesa Reservoir during the mid-1980's, but only the September 1984 pH values were elevated (table 18).

Specific-conductance values for both Iola and Sapinero Basins generally were higher during 1999 when compared to data for 1975, 1983, 1984, and 1985 (table 18). The only statistically significant trend result for specific conductance was for Iola Basin for 1984–99; increasing values over time were indicated (table 20). Trend results for specific conductance in the Gunnison River at County Road 32, the major

Table 18. August and September/October water-quality data for Iola (site BM1) and Sapinero (site BM3) Basins, Blue Mesa Reservoir, for 1975, 1983, 1984, 1985, and 1999

[Site number refers to table 1 and figure 1; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; --, no data; <, less than; data for 1975 are from U.S. Environmental Protection Agency (1977); data for 1983–85 are from the National Park Service]

Date	pH (standard units)	Specific conductance (µS/cm)	Secchi depth (meters)	Total ammonia plus organic nitrogen (mg/L)	Total phosphorus (mg/L)	Dissolved orthophosphate (mg/L)
BLUE MESA RESERVOIR AT IOLA BASIN (SITE BM1)						
August 1975	8.4	187	2.54	0.4	0.014	0.003
August 1984	[1]8.0	[1]138	[1]3.38	--	[1]0.05	[1]0.020
August 1985	8.0	155	4.00	0.05	--	--
August 1999	8.3	203	4.5	0.2	0.008	<0.001
September 1975	8.7	158	2.74	0.3	0.020	0.002
September 1983	7.4	160	3.60	--	--	--
September 1984	8.6	[1]130	4.00	--	[1]0.06	[1]<0.010
September 1985	7.5	--	3.50	--	--	--
October 1999	8.2	204	3.0	0.3	0.033	0.002
BLUE MESA RESERVOIR AT SAPINERO BASIN (SITE BM3)						
August 1975	8.0	156	1.27	0.2	0.012	0.002
August 1983	--	--	--	<1.00	<0.05	0.017
August 1984	[1]8.0	[1]135	[1]3.75	--	[1]0.03	[1]0.010
August 1985	7.6	155	4.00	--	--	--
August 1999	8.2	184	4.5	0.2	0.013	0.001
September 1975	8.4	124	3.51	0.2	0.015	0.002
September 1983	7.6	180	3.00	--	--	--
September 1984	[1]8.4	[1]130	[1]4.00	--	[1]0.10	[1]<0.010
September 1985	--	--	--			
October 1999	7.9	179	3.5	0.1	0.011	0.006

[1]Median value.

inflow to Iola Basin, indicated increasing values for 1987–94 and no trend for 1995–99. No trend was present in the amount of inflow entering Blue Mesa Reservoir for 1984–99. The upward trend in specific conductance in Iola Basin for 1984–99 may be related to the upward trend in specific conductance in the Gunnison River at County Road 32 for 1987–94.

Secchi depth was lowest in Iola Basin during August and September 1975. A statistically significant ($p \leq 0.05$) trend result for 1984–99 indicated increasing values of Secchi depth in Iola Basin over time (table 20). Secchi depth can vary depending on biota and particulate and dissolved matter in the photic zone. For Iola Basin, no correlation was present between Secchi depth and specific conductance for 1984–99, even though an upward trend for that time period was indicated for both properties. The August 1975 Secchi depth in Sapinero Basin also was lower than in other years (table 18). More recently, no trend in Secchi depth in Sapinero Basin was indicated for 1992–99 (table 20).

Nutrients

Total ammonia plus organic nitrogen concentrations were identical or nearly identical in Iola and Sapinero Basins during late summer through early fall for 1975 and 1999 (table 18). Total phosphorus concentrations during late summer through early fall in the two basins were higher during 1984 than during 1975 or 1999 (table 18). Dissolved orthophosphate concentrations in Iola and Sapinero Basin also were higher during August 1983 and(or) August 1984. Total ammonia plus organic nitrogen and total phosphorus data for both basins were tested for trends. A statistically significant ($p \leq 0.05$) result for total phosphorus in Sapinero Basin indicated a decrease in concentration for 1992–99 (table 20).

Results of the seasonal Kendall test for trends in nutrient data for Gunnison River at County Road 32 and Lake Fork of the Gunnison River indicated that the only statistically significant ($p \leq 0.05$) trend present was an upward trend in total phosphorus concentration

Table 19. Phytoplankton genera detected in Blue Mesa Reservoir during 1975, 1983, 1984, 1985, 1998, and 1999, listed in respective phylum

[Data for 1975 and 1983–85 are from Cudlip and others (1987); data for 1998 are from National Park Service (1998b)]

Phytoplankton	1975	1983	1984	1985	1998	1999	Phytoplankton	1975	1983	1984	1985	1998	1999
Phylum Bacillariophyta (Diatoms)							**Phylum Chlorophyta (Green algae)**						
Achnanthes				X			*Ankistrodesmus*		X	X		X	
Amphipleura				X			*Asterococcus*		X				
Amphora		X					*Botryococcus*		X	X	X		
Asterionella	X	X	X	X	X	X	*Chaetophora*		X				
Biddulphia				X			*Characium*		X				
Cocconeis		X		X	X		*Chlamydomonas*		X	X	X		X
Coscinodiscus					X		*Chlorococcum*					X	
Cyclotella			X	X			*Chlorogonium*		X				
Cymatopleura				X			*Closteriopsis*		X				
Cymbella	X			X			*Closterium*		X				
Diatoma				X			*Coelastrum*		X				
Epithemia				X			*Eudorina*		X	X			
Fragilaria	X	X	X	X	X	X	*Gloeococcus*		X				
Gomphonema			X	X			*Gloeocystis*		X		X	X	
Hannaea		X	X	X			*Gongrosira*		X				
Mastogloia				X			*Gonium*		X				
Melosira		X	X	X	X	X	*Kirchneriella*		X			X	
Navicula		X	X	X		X	*Mougeotia*		X	X			
Nitzschia		X	X	X			*Nannochloris*		X				
Pinnularia				X			*Octocystis*		X	X			
Rhoicosphenia				X			*Octosporiella*		X	X			
Rhopalodia			X				*Oedogonium*		X	X			
Stephanodiscus	X	X	X	X	X	X	*Oocystis*	X	X	X			
Surirella				X			*Palmellopsis*		X				
Synedra		X	X	X		X	*Pandorina*		X			X	X
Tabellaria						X	*Pediastrum*		X	X		X	

Table 19. Phytoplankton genera detected in Blue Mesa Reservoir during 1975, 1983, 1984, 1985, 1998, and 1999, listed in respective phylum—Continued

[Data for 1975 and 1983–85 are from Cudlip and others (1987); data for 1998 are from National Park Service (1998b)]

Phytoplankton	1975	1983	1984	1985	1998	1999
Phylum Chrysophyta (Golden-brown algae)						
Chromulina		X				
Chrysamoeba		X	X			
Chrysochromulina			X			
Dinobryon			X		X	X
Mallomonas		X				
Synura			X			
Phylum Cryptophyta (Cryptomonad algae)						
Chroomonas	X					
Cryptomonas	X	X	X	X		
Phylum Cyanophyta (Blue-green algae)						
Anabaena		X	X	X	X	X
Aphanizomenon	X	X	X	X	X	X
Aphanothece		X	X			
Dactylococcopsis			X			
Gomphosphaeria			X			
Microcystis	X	X	X			
Nostoc					X	
Oscillatoria		X				
Pseudoanabaena		X				
Phylum Euglenophyta (Euglenoid algae)						
Colacium		X	X			
Euglena		X	X	X		
Phylum Pyrrophyta (Dinoflagellates)						
Ceratium		X	X		X	X
Phylum Xanthophyta (Yellow-green algae)						
Tribonema		X	X			
Phylum Chlorophyta (green algae)—Continued						
Quadrigula		X			X	
Scenedesmus		X				
Schroederia	X	X	X	X		X
Sphaerocystis		X	X	X		
Spirogyra		X	X			
Spondylosium		X				
Staurastrum	X	X	X	X	X	
Stigeoclonium		X				
Tetraedron	X					
Ulothrix		X	X			
Volvox		X	X			
Volvulina		X	X			

Table 20. Results of seasonal Kendall test for temporal trends in Blue Mesa Reservoir inflow and water-quality parameters for Iola (site BM1) and Sapinero (site BM3) Basins in Blue Mesa Reservoir, Gunnison River at County Road 32 (site BI1), and Lake Fork of the Gunnison River (site BI10)

[Site number refers to table 1 and figure 1; periods are in water years, except for Blue Mesa Reservoir inflow, which is in calendar years; *p*-value is the significance level of the test; BOR, Bureau of Reclamation; NPS, National Park Service; CURE, U.S. Geological Survey and National Park Service data collection in 1999; µS/cm, microsiemens per centimeter at 25 degrees Celsius; m, meter; mg/L, milligrams per liter; slopes are listed only for statistically significant trend results; UCOL, Upper Colorado River Basin National Water-Quality Assessment Program]

Parameter	Period	Source of data	Slope	*p*-Value	Trend direction
BLUE MESA RESERVOIR					
Inflow	1984–99	BOR		0.510	None
BLUE MESA RESERVOIR AT IOLA BASIN (SITE BM1)					
Dissolved oxygen	1984–99	NPS, CURE		0.078	None
pH	1984–99	NPS, CURE		0.980	None
Specific conductance	1984–99	NPS, CURE	4.78 µS/cm per year	0.008	Upward
Secchi depth	1984–99	NPS, CURE	0.080 m per year	0.009	Upward
Chlorophyll-*a*	1984–99	NPS, CURE		0.689	None
Ammonia plus organic nitrogen, total	1987–99	NPS, CURE		0.328	None
Total phosphorus	1987–99	NPS, CURE		0.573	None
BLUE MESA RESERVOIR AT SAPINERO BASIN (SITE BM3)					
Dissolved oxygen	1992–99	NPS, CURE		0.441	None
pH	1992–99	NPS, CURE	0.042 standard units per year	<0.001	Upward
Specific conductance	1992–99	NPS, CURE		0.423	None
Secchi depth	1992–99	NPS, CURE		0.404	None
Chlorophyll-*a*	1992–99	NPS, CURE		0.423	None
Ammonia plus organic nitrogen, total	1992–99	NPS, CURE		0.698	None
Total phosphorus	1992–99	NPS, CURE	–0.018 mg/L per year	0.003	Downward
GUNNISON RIVER AT COUNTY ROAD 32 (SITE BI1)					
Specific conductance	1995–99	UCOL, CURE		0.514	None
	1987–94	NPS	7.80 µS/cm per year	<0.001	Upward
Ammonia plus organic nitrogen, total	1995–99	UCOL, CURE		0.695	None
	1987–94	NPS		0.319	None
Dissolved inorganic nitrogen	1995–99	UCOL, CURE		0.896	None
Total phosphorus	1995–99	UCOL, CURE		0.240	None
	1987–94	NPS	0.028 mg/L per year	<0.001	Upward
Dissolved orthophosphate	1995–99	UCOL, CURE		0.896	None
LAKE FORK OF THE GUNNISON RIVER (SITE BI10)					
Ammonia plus organic nitrogen, total	1995–99	UCOL, CURE		0.462	None
Total phosphorus	1995–99	UCOL, CURE		0.806	None

for Gunnison River at County Road 32 for 1987–94 (table 20). This did not appear to affect Blue Mesa Reservoir, as no trend was present in total phosphorus concentrations for Iola Basin (the basin nearest to the Gunnison River inflow) for 1987–99. Also, there was no correlation between total phosphorus concentrations in the Gunnison River at County Road 32 and chlorophyll-*a* concentrations in Iola Basin for 1984–99.

Data on total phosphorus concentrations for the major inflow to Sapinero Basin, Lake Fork of the Gunnison River, are only available for 1995–99, and no trend was indicated for those data. The downward trend in total phosphorus concentration in Sapinero Basin for 1992–99 does not appear to be related to total phosphorus concentrations in Lake Fork of the Gunnison River.

As stated previously, all three basins in Blue Mesa Reservoir during 1999 were limited in phosphorus during April and nitrogen during November, with possible nitrogen limitation in Sapinero Basin during summer and all three basins during fall. The results for spring and summer of 1999 can be compared with historical data for the same seasons. The limitation of phosphorus during spring 1999 mirrors the phosphorus limitation noted during May and June 1983, 1984, and 1985 (Cudlip and French, 1985). While nitrogen probably was the limiting nutrient in Sapinero Basin during summer 1999, historical data indicate variability in nutrient limitation during summer. For 1983 and 1984, nitrogen was the limiting nutrient during July, and phosphorus was limiting during August. Opposite results prevailed for 1985 with phosphorus limitation during July and nitrogen limitation during August. Nitrogen was the limiting nutrient during August 1975 (U.S. Environmental Protection Agency, 1977).

Phytoplankton

Differences in phytoplankton over time in Blue Mesa Reservoir can be examined in terms of density, genera richness and community structure, and community succession. Mean phytoplankton densities in the three basins were lower during 1999 than those during 1983, 1984, 1985, and 1998 (table 21), and densities were lower during 1998 than during the mid-1980's (National Park Service, 1998b). This decrease in mean phytoplankton density over time may be related to genera richness and nutrients. In comparing phytoplankton data for Blue Mesa Reservoir for 1975, 1983, 1984, 1985, 1998, and 1999, genera richness was greatest during the mid-1980's (fig. 30, table 19). Genera of green algae were most common during 1983 and 1984, whereas diatoms were dominant during 1985 (fig. 31). The mid-1980's were wet years in the Gunnison River Basin. Inflows to Blue Mesa Reservoir during 1983, 1984, and 1985 were higher than those for 1975, 1998, and 1999. The range in maximum daily peak inflows during the mid-1980's was 8,328–16,084 ft^3/s, whereas the range for 1975, 1998, and 1999 was 4,754–7,346 ft^3/s (Bureau of Reclamation, 1975–99). Greater inflows into Blue Mesa Reservoir during the mid-1980's would have increased dissolved nutrient and suspended-sediment loads and provided additional nutrients for phytoplankton, possibly resulting in an increase in mean phytoplankton density and number of genera present in the reservoir.

The phytoplankton community succession observed during 1999 was similar to that during the mid-1980's and 1998 (Cudlip and others, 1987; National Park Service, 1998b). Diatoms were the dominant phytoplankton during the cooler spring and early summer months, whereas the blue-green algae *Aphanizomenon* sp. was dominant during the warmer late summer and fall months. One difference between the 1999 data and historical data was that the diatom *Tabellaria*, a prominent genus during 1999, was not observed during the mid-1980's or 1998. It is normal for species composition to fluctuate from year to year in a water body, as long as the system is not seriously disturbed (Wetzel, 1983).

Chlorophyll-*a*

Finally, current and historical data for Blue Mesa Reservoir can be compared in terms of chlorophyll-*a* and trophic status of the reservoir. Mean chlorophyll-*a* concentrations for the 0–15 m interval in Iola, Cebolla, and Sapinero Basins were determined for the July–October 1985 monthly samples, and the

Table 21. Mean phytoplankton density in Blue Mesa Reservoir by basin for 1983, 1984, 1985, 1998, and 1999

[Site number refers to table 1 and figure 1; algal units/L, algal units per liter; data for 1983–85 are from Cudlip and others (1987); data for 1998 are from National Park Service (1998b)]

Date	Iola Basin (site BM1) (algal units/L)	Cebolla Basin (site BM2) (algal units/L)	Sapinero Basin (site BM3) (algal units/L)
1983: July, August	86,000	66,000	69,000
1984: July–September	3,290,000	386,000	239,000
1985: July–September	8,484,000	4,846,000	16,000
1998: June, July, September	12,091	1,861	3,054
1999: April, August, October	7,919	1,422	1,135

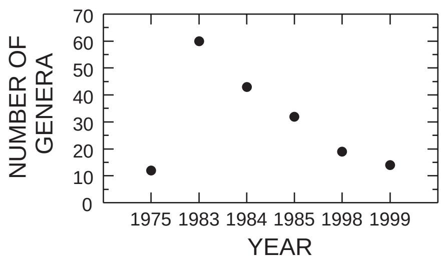

Figure 30. Genera richness in Blue Mesa Reservoir for 1975, 1983, 1984, 1985, 1998, and 1999.

trophic status was determined using Likens' (1975) index. Iola Basin was classified as mesotrophic with a mean chlorophyll-*a* concentration of 4.84 mg/m^3; Cebolla Basin, oligotrophic, 2.58 mg/m^3; and Sapinero Basin, oligotrophic, 1.41 mg/m^3 (Cudlip and French, 1985). In comparing these 1985 results to the sampling results of August and October 1999, the trophic status of the basins did not change between 1985 and 1999. Iola Basin remained mesotrophic with a mean chlorophyll-*a* concentration of 4.54 mg/m^3 for August and October 1999. Cebolla Basin remained oligotrophic with a mean chlorophyll-*a* concentration of 1.49 mg/m^3 for the same months of 1999. This latter value, however, was lower than the chlorophyll-*a* concentration of 2.58 mg/m^3 recorded during 1985 and may be due to the difference in the number of months used in the mean calculations (July–October for 1985 and August and October for 1999) and to year-to-year variability in monthly chlorophyll-*a* concentrations. Sapinero Basin was again oligotrophic with a mean chlorophyll-*a* concentration of 1.46 mg/m^3 for August and October 1999. Cudlip and others (1987) summarized chlorophyll-*a* data for 1982–85 and reported that Blue Mesa Reservoir was mesotrophic over the 3-year time period. The reservoir also was mesotrophic during 1975 (U.S. Environmental Protection Agency, 1977) and 1999. Although the trophic status of the reservoir remained constant over time and mean chlorophyll-*a* concentrations were similar between 1985 and 1999, the annual variability in chlorophyll-*a* concentration was much greater for Iola Basin after 1985 (fig. 32). Annual chlorophyll-*a* data for Sapinero Basin do not begin until 1992.

Nutrient Enrichment

Results of the comparison and trend-analysis examination of historical and current (as of 1999) data for Blue Mesa Reservoir indicate that nutrient enrichment is not occurring in the reservoir. For Iola Basin, no trends were detected in total ammonia plus organic nitrogen and total phosphorus concentrations for 1987–99, even though an upward trend in total phosphorus was detected in the Gunnison River at County Road 32 for 1987–94. For Sapinero Basin, no trend was detected in total ammonia plus nitrogen concentrations for 1992–99, whereas there was a downward trend in total phosphorus concentrations for the same time period. No trend was detected in these two nutrients in the Lake Fork of the Gunnison River for 1995–99. A comparison of chlorophyll-*a* data did not indicate an increase in reservoir productivity. Finally, the trophic status of the reservoir during 1999 was similar to that observed during 1975 and the mid-1980's. It does not appear that increasing development and land-use changes in the upper Gunnison River Basin have affected nutrient levels in Blue Mesa Reservoir. While in some cases a bloom of *Aphanizomenon* sp. can indicate eutrophic conditions, the *Aphanizomenon* sp.

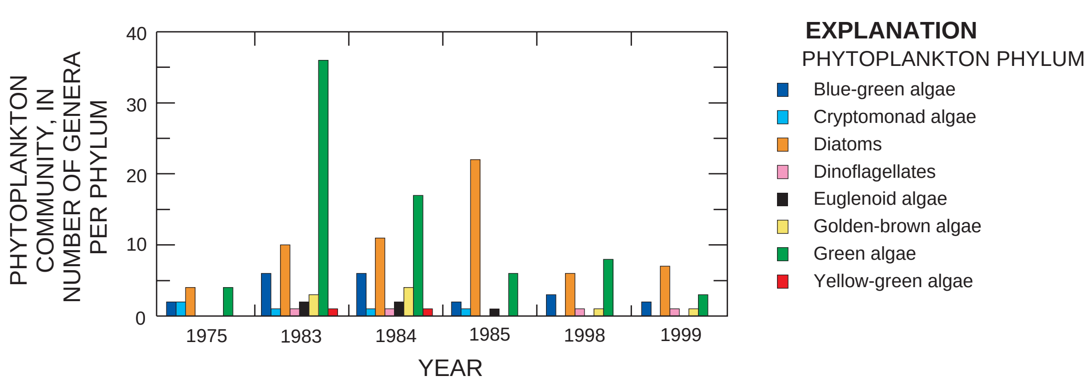

Figure 31. Phytoplankton community in Blue Mesa Reservoir for 1975, 1983, 1984, 1985, 1998, and 1999.

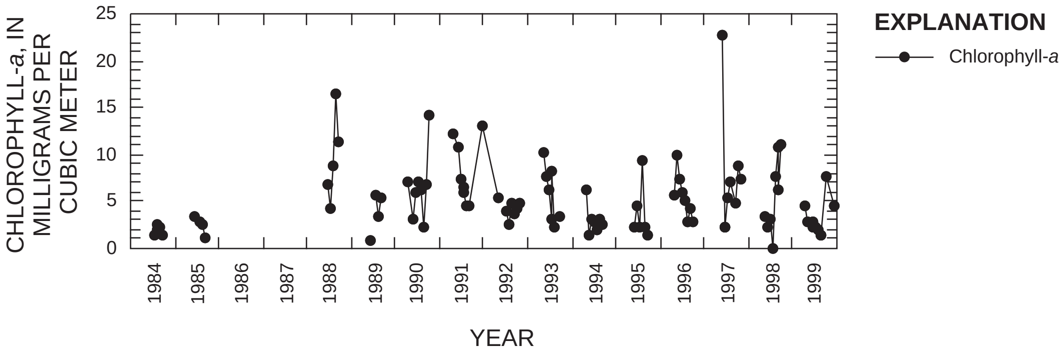

Figure 32. Chlorophyll-*a* concentrations in Blue Mesa Reservoir at Iola Basin (site BM1), 1984–99.

bloom observed in Iola Basin during fall 1999 probably was related more to favorable environmental conditions and biological factors (including warm water, ability to fix atmospheric nitrogen, and regulation of position in the water column) than excess nutrients. A bloom of *Aphanizomenon* sp. in Iola Basin is not a unique occurrence; a bloom was observed as early as 1967 (Wiltzius, 1974).

SUMMARY

To assess the current (as of 1999) limnological characteristics of Blue Mesa, Morrow Point, and Crystal Reservoirs and to carry out a 25-year retrospective of nutrient conditions in Blue Mesa Reservoir, the U.S. Geological Survey and the National Park Service conducted a water-quality investigation from April through December 1999. Samples were collected from reservoir, inflow, and outflow sites four times during 1999. Reservoir samples for nutrient analysis were collected from multiple depths at three sites on Blue Mesa and Morrow Point Reservoirs and at one site on Crystal Reservoir. Phytoplankton and chlorophyll-*a* samples were collected in the reservoirs from near-surface waters. Total nitrogen and phosphorus concentrations in the reservoirs were low. Median concentrations were less than 0.4 and 0.06 milligram per liter, respectively. Nutrient concentrations for most summer and fall samples collected at depth were greater than photic-zone samples. The phytoplankton community and density in each reservoir were affected by water temperature, nutrients, and water residence time. In each reservoir, diatoms dominated with cooler water temperatures—during spring and early winter in Blue Mesa Reservoir and throughout the year in Morrow Point and Crystal Reservoirs. Seasonally, both Blue Mesa and Morrow Point Reservoirs had their lowest phytoplankton densities during summer when inorganic nitrogen was not detected and was fully utilized by biota. Density in Crystal Reservoir was highest during summer when orthophosphate was fully utilized and inorganic nitrogen was not. With low inorganic nitrogen concentrations and warmer temperatures in Blue Mesa Reservoir during summer and fall, blue-green algae were the dominant phytoplankton. Spatially, phytoplankton abundance was highest in Blue Mesa Reservoir and lowest in Crystal Reservoir. In Blue Mesa Reservoir, the longer residence time (greater than 6 months) and warmer water temperatures presented favorable conditions for phytoplankton growth and development. In Morrow and Crystal Reservoirs, low phytoplankton abundance was probably due to short residence times and cooler water temperatures. The short residence times of weeks and days, respectively, would limit the time phytoplankton had to reproduce and would limit the population size. Also, the short residence times would not be long enough to allow the deep-discharge waters to warm, and cooler water temperatures would limit phytoplankton growth and development. Chlorophyll-*a* concentrations in the reservoirs reflected productivity levels. The mean chlorophyll-*a* concentration was higher in Blue Mesa Reservoir than Morrow and Crystal Reservoirs. Using the classification system developed by Likens (1975), the trophic status of Blue Mesa Reservoir varied along an upstream-to-downstream gradient, with mesotrophic conditions and more productive waters in the upstream portions of the reservoir and oligotrophic conditions downstream. Both Morrow and Crystal Reservoirs were oligotrophic. Trophic-state indices for total phosphorus, chlorophyll-*a*, and Secchi depth ranged between 29 and 55. Only Iola and Cebolla Basins in Blue Mesa Reservoir had total phosphorus and chlorophyll-*a* indices above 50, reflecting the mesotrophic conditions in the two basins. Because there are no major impoundments directly upstream from Blue Mesa Reservoir, nutrient inflows to the reservoir varied seasonally, with a lower nutrient supply occurring after spring snowmelt. For Morrow Point and Crystal Reservoirs, there was a steady inflow of nutrients during the sampling period. Nutrient concentrations in the deep-discharge waters from the respective upstream impoundment were fairly consistent for all four sampling events, and nutrient concentrations in the two reservoirs were mostly dependent on upstream reservoir conditions rather than seasonal stream inflows. Among the physical properties and nutrient constituents studied for the inflows for all three reservoirs, only total phosphorus concentrations were elevated; other parameters including dissolved oxygen, pH, and nitrogen constituents were within water-quality standards for the State of Colorado. Total phosphorus loads, however, would be low in most stream inflows because of small streamflow amounts. For Blue Mesa Reservoir, a comparison of 1999 and historical chlorophyll-*a* and nutrient data revealed that productivity in the reservoir has not changed over time, and the reservoir has not become more enriched with nutrients.

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SUPPLEMENTAL DATA

Table 22. Reservoir profile measurements, Blue Mesa Reservoir at Iola Basin (site BM1), April–November 1999

[Site number refers to table 1 and figure 1; C, Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)
APRIL 20, 1999, SECCHI-DISC DEPTH, 3.0 METERS					**AUGUST 19, 1999, SECCHI-DISC DEPTH, 4.5 METERS**				
1	5.7	9.7	8.3	225	1	19.3	6.8	8.3	203
2	5.7	9.6	8.3	227	2	19.0	6.9	8.3	204
3	5.7	9.6	8.3	226	3	19.0	6.8	8.3	202
4	5.7	9.6	8.3	228	4	18.9	7.0	8.2	203
5	5.7	9.6	8.3	227	5	18.9	6.8	8.3	204
6	5.7	9.5	8.3	227	6	18.8	6.9	8.3	204
7	5.7	9.5	8.3	227	7	18.7	6.7	8.3	205
8	5.7	9.5	8.3	226	8	18.7	6.5	8.2	205
9	5.7	9.5	8.3	224	9	18.6	6.4	8.2	203
10	5.7	9.4	8.3	225	10	18.4	6.3	8.2	205
11	5.7	9.5	8.3	226	11	17.0	6.0	8.0	201
12	5.6	9.4	8.3	227	12	16.6	6.0	8.0	202
13	5.6	9.3	8.3	226	13	16.2	5.9	8.0	202
14	5.5	9.2	8.3	227	14	16.0	5.8	7.9	202
15	5.5	9.2	8.3	227	15	15.7	5.6	7.9	202
16	5.5	9.2	8.3	224	16	15.4	5.5	7.8	202
					17	15.2	5.3	7.8	204
					18	15.1	5.6	7.8	204
					19	14.9	4.3	7.7	206
					20	14.4	4.0	7.6	209
					21.4	14.4	3.8	7.6	210
OCTOBER 6, 1999, SECCHI-DISC DEPTH, 3.0 METERS					**NOVEMBER 30, 1999, SECCHI-DISC DEPTH, 4.0 METERS**				
1	14.2	7.6	8.2	204	1	6.7	8.7	7.7	191
2	14.2	7.6	8.2	204	2	6.7	8.7	7.7	191
3	14.2	7.6	8.2	204	3	6.7	8.7	7.7	191
4	14.2	7.6	8.2	204	4	6.6	8.7	7.7	191
5	14.2	7.6	8.3	204	5	6.5	8.6	7.7	192
6	14.2	7.6	8.2	204	6	6.5	8.6	7.7	192
7	14.2	7.6	8.2	205	7	6.4	8.6	7.7	192
8	14.2	7.5	8.2	204	8	6.3	8.5	7.7	192
9	14.1	7.6	8.2	204	9	6.3	8.5	7.7	192
10	14.1	7.6	8.2	204	10	6.3	8.5	7.7	193
11	14.1	7.6	8.3	204	11	6.2	8.5	7.7	193
12	14.1	7.6	8.2	205	12	6.2	8.5	7.7	192
13	14.1	7.6	8.3	205	13	5.9	8.6	7.6	196
14	14.1	7.6	8.3	204	14	5.6	8.7	7.6	198
15	14.1	7.6	8.3	204	15	5.4	8.7	7.6	199
16	14.1	7.6	8.3	205	16	4.8	8.7	7.6	204
17	14.1	7.6	8.3	205	17	4.4	8.5	7.4	209
18	14.1	7.6	8.3	205					
19	14.1	7.5	8.2	205					
20	14.0	7.4	8.2	205					
21	10.8	7.6	7.9	215					

Table 23. Reservoir profile measurements, Blue Mesa Reservoir at Cebolla Basin (site BM2), April–November 1999

[Site number refers to table 1 and figure 1; C, Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)
APRIL 20, 1999, SECCH-DISC DEPTH, 3.0 METERS					**AUGUST 19, 1999, SECCHI-DISC DEPTH, 5.0 METERS**				
1	5.1	10.0	8.4	221	1	19.0	6.5	8.2	190
2	5.0	10.0	8.4	220	2	19.0	6.5	8.2	191
3	5.0	10.0	8.4	218	3	19.0	6.5	8.2	189
4	5.0	9.9	8.4	220	4	19.0	7.0	8.2	189
5	5.0	9.9	8.4	218	5	19.0	7.1	8.3	190
6	5.0	9.9	8.4	218	6	19.0	7.0	8.3	192
7	5.0	9.9	8.4	219	7	19.0	7.0	8.3	191
8	5.0	9.8	8.4	219	8	19.0	7.0	8.3	191
9	5.0	9.8	8.4	221	9	19.0	6.9	8.3	192
10	5.0	9.8	8.4	220	10	17.3	5.6	7.9	202
11	5.0	9.8	8.4	219	11	16.8	5.4	7.8	203
12	5.0	9.7	8.4	218	12	16.3	5.2	7.7	205
13	5.0	9.7	8.4	219	13	16.0	5.1	7.7	206
14	5.0	9.7	8.4	219	14	15.8	5.0	7.7	204
15	5.0	9.7	8.4	220	15	15.5	5.0	7.6	200
16	5.0	9.7	8.4	218	16	15.3	4.9	7.6	204
17	4.9	9.7	8.4	219	17	15.2	4.8	7.6	209
18	4.9	9.7	8.4	219	18	14.8	4.7	7.6	195
19	4.9	9.7	8.4	218	19	14.6	4.7	7.6	199
20	4.9	9.7	8.4	220	20	14.4	4.8	7.6	193
25	4.8	9.6	8.4	219	25	12.7	5.2	7.6	185
30	4.8	9.6	8.4	219	30	11.2	5.0	7.6	188
35	4.7	9.6	8.4	219	35	10.3	4.4	7.5	191
40	4.7	9.6	8.4	218	40	9.2	4.1	7.5	196
45	4.7	9.6	8.4	217	45	7.8	4.3	7.5	196
50	4.6	9.5	8.4	218	50	7.2	4.5	7.5	196
					55	7.0	4.5	7.5	196
					60	6.8	4.2	7.5	196
					60.9	6.8	4.2	7.4	196

Table 23. Reservoir profile measurements, Blue Mesa Reservoir at Cebolla Basin (site BM2), April–November 1999—Continued

[Site number refers to table 1 and figure 1; C, Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)
OCTOBER 6, 1999, SECCHI-DISC DEPTH, 5.0 METERS					NOVEMBER 30, 1999, SECCHI-DISC DEPTH, 4.0 METERS				
1	14.5	6.8	8.0	197	1	7.6	8.9	7.8	191
2	14.4	6.8	8.0	197	2	7.6	8.7	7.8	191
3	14.4	6.8	8.0	197	3	7.7	8.7	7.8	191
4	14.4	6.7	8.0	197	4	7.7	8.8	7.8	190
5	14.4	6.6	8.0	197	5	7.6	8.9	7.8	190
6	14.4	6.7	8.0	197	6	7.7	8.9	7.8	191
7	14.4	6.7	8.0	198	7	7.7	8.9	7.8	191
8	14.4	6.6	8.0	197	8	7.7	8.4	7.8	191
9	14.4	6.6	8.0	197	9	7.7	8.1	7.8	191
10	14.4	6.6	8.0	197	10	7.7	8.0	7.8	191
11	14.4	6.6	8.0	197	11	7.7	8.0	7.8	191
12	14.4	6.6	8.0	198	12	7.7	8.0	7.8	191
13	14.4	6.6	8.0	198	13	7.6	8.0	7.8	191
14	14.4	6.6	8.0	197	14	7.6	8.0	7.8	191
15	14.4	6.6	8.0	198	15	7.7	8.0	7.8	191
16	14.4	6.6	8.0	198	16	7.7	8.0	7.8	191
17	14.4	6.5	8.0	198	17	7.7	8.0	7.8	191
18	14.4	6.6	8.0	198	18	7.6	7.9	7.8	191
19	14.4	6.6	8.0	198	19	7.6	8.0	7.8	191
20	14.4	6.6	8.0	197	20	7.6	8.0	7.8	191
25	14.4	6.6	8.0	197	25	7.6	8.0	7.8	191
30	13.8	6.0	7.9	203	30	7.3	7.9	7.8	192
35	13.0	4.3	7.5	205	35	7.0	7.9	7.8	193
40	11.8	2.0	7.2	212	40	6.6	7.9	7.7	194
45	8.8	1.5	7.1	208	45	6.4	7.9	7.7	195
50	7.4	2.6	7.1	205	50	6.3	7.8	7.7	195
55	7.2	2.3	7.0	206	54.3	6.3	6.9	7.7	196
56	7.2	2.1	7.2	207					

Table 24. Reservoir profile measurements, Blue Mesa Reservoir at Sapinero Basin (site BM3), April–November 1999

[Site number refers to table 1 and figure 1; C, Celsius; mg/L, milligrams per liter; μS/cm, microsiemens per centimeter at 25 degrees Celsius]

Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (μS/cm)	Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (μS/cm)
APRIL 20, 1999, SECCHI-DISC DEPTH, 3.5 METERS					**AUGUST 19, 1999, SECCHI-DISC DEPTH, 4.5 METERS**				
1	5.1	9.8	8.4	213	1	18.9	7.8	8.2	184
2	4.8	9.8	8.4	213	2	18.9	6.8	8.3	183
3	4.7	9.8	8.4	212	3	18.9	6.8	8.3	185
4	4.7	9.7	8.4	214	4	18.8	6.8	8.3	186
5	4.6	9.7	8.4	213	5	18.8	6.9	8.3	184
6	4.6	9.6	8.4	213	6	18.7	6.8	8.3	186
7	4.5	9.6	8.3	213	7	18.7	6.8	8.3	185
8	4.5	9.6	8.3	214	8	18.7	6.9	8.3	185
9	4.5	9.5	8.3	214	9	18.6	6.8	8.3	184
10	4.5	9.6	8.3	213	10	18.5	6.6	8.2	185
11	4.5	9.5	8.3	214	11	17.6	5.6	8.0	177
12	4.5	9.5	8.3	211	12	16.7	5.6	7.9	161
13	4.5	9.5	8.3	213	13	16.0	5.7	7.8	151
14	4.4	9.5	8.3	214	14	15.4	6.1	7.8	146
15	4.4	9.5	8.3	212	15	15.3	5.9	7.8	145
16	4.4	9.5	8.3	213	16	15.2	5.4	7.7	144
17	4.4	9.5	8.3	211	17	14.9	5.6	7.7	142
18	4.4	9.5	8.3	211	18	14.8	5.5	7.8	143
19	4.4	9.5	8.3	212	19	14.8	5.2	7.7	157
20	4.4	9.5	8.3	214	20	14.6	6.0	7.6	146
25	4.4	9.4	8.3	212	25	13.2	5.8	7.6	137
30	4.3	9.4	8.3	212	30	11.2	6.0	7.7	145
35	4.3	9.4	8.3	212	35	10.4	5.8	7.7	166
40	4.3	9.4	8.3	211	40	9.3	5.2	7.6	187
45	4.3	9.4	8.3	212	45	8.0	5.8	7.6	186
50	4.2	9.4	8.3	212	50	7.1	5.9	7.7	195
55	4.2	9.4	8.3	212	55	6.6	6.6	7.7	193
60	4.2	9.4	8.3	212	60	6.3	6.9	7.8	192
65	4.3	9.3	8.3	212	65	6.1	6.7	7.8	193
					70	6.0	6.6	7.8	194
					73	5.9	6.7	7.8	193

Table 24. Reservoir profile measurements, Blue Mesa Reservoir at Sapinero Basin (site BM3), April–November 1999—Continued

[Site number refers to table 1 and figure 1; C, Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)
OCTOBER 6, 1999, SECCHI-DISC DEPTH, 3.5 METERS					NOVEMBER 30, 1999, SECCHI-DISC DEPTH, 5.0 METERS				
1	14.3	6.4	7.9	179	1	8.2	7.3	7.5	187
2	14.3	6.4	7.9	179	2	8.1	7.4	7.5	188
3	14.2	6.3	7.8	180	3	8.1	7.4	7.5	187
4	14.2	6.2	7.8	180	4	8.1	7.3	7.5	188
5	14.2	6.1	7.8	180	5	8.1	7.3	7.6	188
6	14.2	6.1	7.8	181	6	8.1	7.3	7.6	188
7	14.2	6.0	7.8	181	7	8.1	7.3	7.5	188
8	14.2	6.0	7.8	180	8	8.1	7.2	7.6	188
9	14.2	6.0	7.8	180	9	8.1	7.2	7.6	188
10	14.2	6.1	7.8	180	10	8.1	7.2	7.6	188
11	14.2	6.1	7.8	180	11	8.1	7.2	7.6	188
12	14.2	6.1	7.8	180	12	8.1	7.2	7.6	188
13	14.1	6.1	7.8	180	13	8.1	7.2	7.6	188
14	14.1	6.1	7.7	181	14	8.1	7.1	7.6	188
15	14.1	6.1	7.8	180	15	8.1	7.2	7.6	187
16	14.1	6.1	7.8	181	16	8.1	7.3	7.6	187
17	14.1	6.0	7.8	181	17	8.1	7.2	7.6	187
18	14.1	6.0	7.7	181	18	8.1	7.2	7.6	187
19	14.1	6.0	7.7	181	19	8.1	7.2	7.6	187
20	14.1	6.0	7.7	182	20	8.1	7.2	7.6	187
25	14.1	6.0	7.7	182	25	8.1	7.2	7.6	187
30	14.0	5.8	7.7	182	30	8.1	7.1	7.6	188
35	13.1	3.8	7.3	194	35	8.0	6.9	7.6	189
40	11.4	4.0	7.2	186	40	8.0	6.8	7.5	190
45	8.6	4.1	7.2	199	45	7.8	6.6	7.5	192
50	7.4	4.3	7.2	203	50	7.7	6.3	7.4	193
55	6.6	5.8	7.3	202	55	6.7	4.6	7.1	195
60	6.3	6.1	7.4	202	60	6.4	4.8	7.1	194
65	6.1	6.3	7.4	201	65	6.2	5.0	7.1	195
68.5	6.0	6.4	7.4	201	70	6.0	4.9	7.1	196
					75	5.9	4.5	7.0	197
					79	5.8	3.6	7.0	198

Table 25. Nitrogen and phosphorus concentrations in Blue Mesa Reservoir, April–November 1999

[Site number refers to table 1 and figure 1; <, less than; E, estimated]

Date	Time	Sampling depth (feet)	Concentration, in milligrams per liter											
			Nitrogen, ammonia, dissolved	Nitrogen, un-ionized ammonia, dissolved[1]	Nitrogen, nitrite, dissolved	Nitrogen, nitrate + nitrite, dissolved	Nitrogen, nitrate, dissolved[2]	Nitrogen, inorganic, dissolved[3]	Nitrogen, ammonia + organic, dissolved	Nitrogen, ammonia + organic, total	Nitrogen, total[4]	Ortho-phosphate, dissolved	Phos-phorus, dissolved	Phos-phorus, total
BLUE MESA RESERVOIR AT IOLA BASIN (SITE BM1)														
04/20/99	0845	2	0.002	<0.001	<0.001	0.07	0.07	0.07	0.1	0.2	0.3	0.003	0.006	0.02
	0900	26	0.003	<0.001	<0.001	0.07	0.07	0.07	0.1	0.2	0.3	0.003	0.006	0.029
08/19/99	1310	2	<0.002	<0.001	<0.001	<0.005	<0.005	<0.005	0.2	0.2	0.2	<0.001	0.007	0.008
	1350	17	<0.002	<0.001	<0.001	<0.005	<0.005	<0.005	0.2	0.2	0.2	<0.001	0.006	0.007
	1400	35	<0.002	<0.001	0.001	<0.005	<0.005	<0.005	0.2	0.2	0.2	0.002	0.007	0.007
	1420	76	0.002	<0.001	<0.001	0.073	0.073	0.075	0.2	0.3	0.4	0.028	0.031	0.041
10/06/99	1025	2	<0.002	<0.001	<0.001	<0.005	<0.005	<0.005	0.2	0.3	0.3	0.002	E 0.005	0.033
	1035	68	<0.002	<0.001	<0.001	<0.005	<0.005	<0.005	0.1	0.2	0.2	0.002	0.006	0.012
11/30/99	0840	2	<0.002	<0.001	<0.001	0.005	0.005	0.005	<0.1	0.2	0.2	0.001	0.01	0.018
	0851	16	<0.002	<0.001	<0.001	0.008	0.008	0.008	<0.1	0.2	0.2	0.002	0.009	0.021
	0900	55	0.002	<0.001	<0.001	0.015	0.015	0.017	E 0.1	0.1	0.1	0.005	0.014	0.021
BLUE MESA RESERVOIR AT CEBOLLA BASIN (SITE BM2)														
04/20/99	0955	2	0.004	<0.001	<0.001	0.07	0.07	0.07	0.1	0.2	0.3	0.001	<0.004	0.013
	1010	90	0.004	<0.001	<0.001	0.08	0.08	0.08	0.1	0.2	0.3	0.002	<0.004	0.015
08/19/99	0830	2	<0.002	<0.001	<0.001	<0.005	<0.005	<0.005	0.1	0.2	0.2	<0.001	0.006	0.026
	0840	17	0.003	<0.001	<0.001	<0.005	<0.005	<0.005	0.1	0.2	0.2	<0.001	0.006	0.011
	0850	37	0.004	<0.001	0.001	<0.005	<0.005	<0.005	0.1	0.2	0.2	0.001	0.006	0.008
	0930	208	0.003	<0.001	0.001	0.14	0.139	0.14	0.1	0.1	0.2	0.031	0.031	0.037
10/06/99	1120	2	<0.002	<0.001	0.001	<0.005	<0.005	<0.005	0.2	0.2	0.2	0.008	0.011	0.015
	1140	164	0.002	<0.001	0.001	0.16	0.159	0.16	0.2	0.2	0.4	0.041	0.045	0.053
11/30/99	0945	2	<0.002	<0.001	<0.001	0.007	0.007	0.007	E 0.09	0.1	0.1	0.001	0.009	0.015
	0950	16	<0.002	<0.001	<0.001	0.006	0.006	0.006	0.1	0.2	0.2	<0.001	0.008	0.017
	1010	187	0.004	<0.001	<0.001	0.008	0.008	0.012	0.2	0.2	0.2	0.004	0.012	0.025

Table 25. Nitrogen and phosphorus concentrations in Blue Mesa Reservoir, April–November 1999—Continued

[Site number refers to table 1 and figure 1; <, less than; E, estimated]

Date	Time	Sampling depth (feet)	Concentration, in milligrams per liter											
			Nitrogen, ammonia, dissolved	Nitrogen, un-ionized ammonia, dissolved[1]	Nitrogen, nitrite, dissolved	Nitrogen, nitrate + nitrite, dissolved	Nitrogen, nitrate, dissolved[2]	Nitrogen, inorganic, dissolved[3]	Nitrogen, ammonia + organic, dissolved	Nitrogen, ammonia + organic, total	Nitrogen, total[4]	Ortho-phosphate, dissolved	Phos-phorus, dissolved	Phos-phorus, total
BLUE MESA RESERVOIR AT SAPINERO BASIN (SITE BM3)														
04/20/99	1055	2	0.005	<0.001	0.001	0.07	0.069	0.08	0.1	0.1	0.2	0.004	<0.004	0.011
	1125	100	0.004	<0.001	<0.001	0.08	0.08	0.08	0.1	0.2	0.3	0.004	<0.005	0.02
08/19/99	1020	2	0.005	<0.001	0.001	<0.005	<0.005	0.006	0.2	0.2	0.2	0.001	0.005	0.013
	1040	18	0.003	<0.001	0.001	<0.005	<0.005	<0.005	0.1	0.2	0.2	0.001	0.005	0.022
	1100	37	0.004	<0.001	<0.001	<0.005	<0.005	<0.005	0.2	0.2	0.2	0.001	0.004	0.01
	1135	330	0.002	<0.001	<0.001	0.11	0.11	0.11	[5]0.2	[5]0.1	0.2	0.028	0.034	0.039
10/06/99	1230	2	<0.002	<0.001	0.001	<0.005	<0.005	<0.005	0.1	0.1	0.1	0.006	0.008	0.011
	1300	318	<0.002	<0.001	0.001	0.099	0.098	0.099	0.1	0.2	0.3	0.026	0.027	0.033
11/30/99	1045	2	<0.002	<0.001	<0.001	0.031	0.031	0.031	[6]0.3	[6]0.2	[6]0.2	0.007	0.015	0.02
	1055	16	<0.002	<0.001	<0.001	0.031	0.031	0.031	[6]0.2	[6]0.1	[6]0.1	0.007	0.013	0.02
	1115	278	<0.002	<0.001	<0.001	0.11	0.11	0.11	0.1	E 0.1	E 0.2	0.028	0.035	0.04

[1]Calculated from the ammonia concentrations and pH, temperature, and an equilibrium constant (U.S. Geological Survey Office of Water Quality Technical Memorandum No. 93.12, 1993, URL http://water.usgs.gov/admin/memo/QW/qw93.12.html, accessed February 7, 2002).

[2]Dissolved nitrate plus nitrite minus nitrite.

[3]Calculated as the sum of dissolved ammonia and dissolved nitrate plus nitrite. See table 4.

[4]Calculated as the sum of total ammonia plus organic nitrogen and dissolved nitrate plus nitrite. See table 4.

[5]Based on variability in the laboratory method, there is no significant difference between the concentration of (1) dissolved ammonia plus organic nitrogen and (2) total ammonia plus organic nitrogen (D.K. Mueller, U.S. Geological Survey, oral commun., 2002).

[6]Based on variability in the laboratory method, there is no significant difference between the concentration of (1) dissolved ammonia plus organic nitrogen, (2) total ammonia plus organic nitrogen, and (3) total nitrogen (D.K. Mueller, U.S. Geological Survey, oral commun., 2002).

Table 26. Phytoplankton taxonomic list, Curecanti National Recreation Area, April–December 1999

[Site number refers to table 1 and figure 1]

Phylum	Family	Genus
	BLUE MESA RESERVOIR AT IOLA BASIN (SITE BM1)	
Bacillariophyta	Coscinodiscaceae	*Melosira*
Bacillariophyta	Fragilariaceae	*Asterionella*
Bacillariophyta	Fragilariaceae	*Fragilaria*
Bacillariophyta	Fragilariaceae	*Tabellaria*
Bacillariophyta	Naviculaceae	*Navicula*
Chlorophyta	Chlorococcaceae	*Schroederia*
Chrysophyta	Dinobryaceae	*Dinobryon*
Cyanophyta	Nostocaceae	*Anabaena*
Cyanophyta	Nostocaceae	*Aphanizomenon*
Pyrrophyta	Ceratiaceae	*Ceratium*
	BLUE MESA RESERVOIR AT CEBOLLA BASIN (SITE BM2)	
Bacillariophyta	Coscinodiscaceae	*Melosira*
Bacillariophyta	Coscinodiscaceae	*Stephanodiscus*
Bacillariophyta	Fragilariaceae	*Asterionella*
Bacillariophyta	Fragilariaceae	*Fragilaria*
Bacillariophyta	Fragilariaceae	*Synedra*
Bacillariophyta	Fragilariaceae	*Tabellaria*
Bacillariophyta	Naviculaceae	*Navicula*
Chlorophyta	Hydrodictyaceae	*Pandorina*
Chrysophyta	Dinobryaceae	*Dinobryon*
Cyanophyta	Nostocaceae	*Anabaena*
Cyanophyta	Nostocaceae	*Aphanizomenon*
Pyrrophyta	Ceratiaceae	*Ceratium*
	BLUE MESA RESERVOIR AT SAPINERO BASIN (SITE BM3)	
Bacillariophyta	Coscinodiscaceae	*Melosira*
Bacillariophyta	Coscinodiscaceae	*Stephanodiscus*
Bacillariophyta	Fragilariaceae	*Asterionella*
Bacillariophyta	Fragilariaceae	*Fragilaria*
Bacillariophyta	Fragilariaceae	*Synedra*
Bacillariophyta	Fragilariaceae	*Tabellaria*
Bacillariophyta	Naviculaceae	*Navicula*
Chlorophyta	Chlamydomonadaceae	*Chlamydomonas*
Chlorophyta	Chlorococcaceae	*Schroederia*
Chlorophyta	Hydrodictyaceae	*Pandorina*
Chrysophyta	Dinobryaceae	*Dinobryon*
Cyanophyta	Nostocaceae	*Aphanizomenon*
Pyrrophyta	Ceratiaceae	*Ceratium*
	MORROW POINT RESERVOIR ABOVE PINE CREEK (SITE MP1)	
Bacillariophyta	Coscinodiscaceae	*Melosira*
Bacillariophyta	Coscinodiscaceae	*Stephanodiscus*
Bacillariophyta	Fragilariaceae	*Asterionella*
Bacillariophyta	Fragilariaceae	*Fragilaria*
Bacillariophyta	Fragilariaceae	*Tabellaria*
Bacillariophyta	Naviculaceae	*Navicula*
Cyanophyta	Nostocaceae	*Aphanizomenon*

Table 26. Phytoplankton taxonomic list, Curecanti National Recreation Area, April–December 1999—Continued

[Site number refers to table 1 and figure 1]

Phylum	Family	Genus
MORROW POINT RESERVOIR AT KOKANEE BAY (SITE MP2)		
Bacillariophyta	Coscinodiscaceae	*Melosira*
Bacillariophyta	Coscinodiscaceae	*Stephanodiscus*
Bacillariophyta	Fragilariaceae	*Asterionella*
Bacillariophyta	Fragilariaceae	*Fragilaria*
Bacillariophyta	Fragilariaceae	*Tabellaria*
Bacillariophyta	Naviculaceae	*Navicula*
Chlorophyta	Chlorococcaceae	*Schroederia*
Chrysophyta	Dinobryaceae	*Dinobryon*
Cyanophyta	Nostocaceae	*Aphanizomenon*
MORROW POINT RESERVOIR OFF HERMITS REST (SITE MP3)		
Bacillariophyta	Coscinodiscaceae	*Melosira*
Bacillariophyta	Coscinodiscaceae	*Stephanodiscus*
Bacillariophyta	Fragilariaceae	*Asterionella*
Bacillariophyta	Fragilariaceae	*Fragilaria*
Bacillariophyta	Fragilariaceae	*Tabellaria*
Bacillariophyta	Naviculaceae	*Navicula*
Chlorophyta	Gamophyceae	*Spirogyra*
Cyanophyta	Nostocaceae	*Aphanizomenon*
CRYSTAL RESERVOIR NEAR CRYSTAL DAM (SITE CR1)		
Bacillariophyta	Coscinodiscaceae	*Melosira*
Bacillariophyta	Coscinodiscaceae	*Stephanodiscus*
Bacillariophyta	Fragilariaceae	*Asterionella*
Bacillariophyta	Fragilariaceae	*Fragilaria*
Bacillariophyta	Fragilariaceae	*Tabellaria*
Bacillariophyta	Naviculaceae	*Navicula*
Chlorophyta	Chlorococcaceae	*Schroederia*
Chrysophyta	Dinobryaceae	*Dinobryon*
Cyanophyta	Nostocaceae	*Aphanizomenon*
Pyrrophyta	Ceratiaceae	*Ceratium*

Table 27. Number of phytoplankton detected in Blue Mesa Reservoir, April–November 1999

[Algal units/L, algal units per liter; site number refers to table 1 and figure 1]

Phylum	Family	Genus	Algal units/L	Phylum	Family	Genus	Algal units/L
		BLUE MESA RESERVOIR AT IOLA BASIN (SITE BM1)					
	April 20, 1999				**October 6, 1999**		
Bacillariophyta	Coscinodiscaceae	*Melosira*	77	Bacillariophyta	Fragilariaceae	*Asterionella*	75
Bacillariophyta	Fragilariaceae	*Asterionella*	821	Bacillariophyta	Fragilariaceae	*Tabellaria*	298
Bacillariophyta	Fragilariaceae	*Fragilaria*	129	Cyanophyta	Nostocaceae	*Anabaena*	298
Bacillariophyta	Fragilariaceae	*Tabellaria*	209	Cyanophyta	Nostocaceae	*Aphanizomenon*	21,259
Chrysophyta	Dinobryaceae	*Dinobryon*	338		**November 30, 1999**		
	August 18, 1999			Bacillariophyta	Coscinodiscaceae	*Melosira*	5,818
Bacillariophyta	Coscinodiscaceae	*Melosira*	3	Bacillariophyta	Fragilariaceae	*Asterionella*	50
Bacillariophyta	Fragilariaceae	*Tabellaria*	3	Bacillariophyta	Fragilariaceae	*Tabellaria*	845
Bacillariophyta	Naviculaceae	*Navicula*	7	Bacillariophyta	Naviculaceae	*Navicula*	50
Chlorophyta	Chlorococcaceae	*Schroederia*	3	Cyanophyta	Nostocaceae	*Anabaena*	50
Cyanophyta	Nostocaceae	*Anabaena*	10				
Cyanophyta	Nostocaceae	*Aphanizomenon*	223				
Pyrrophyta	Ceratiaceae	*Ceratium*	3				
		BLUE MESA RESERVOIR AT CEBOLLA BASIN (SITE BM2)					
	April 20, 1999				**October 6, 1999**		
Bacillariophyta	Coscinodiscaceae	*Melosira*	157	Bacillariophyta	Coscinodiscaceae	*Melosira*	42
Bacillariophyta	Fragilariaceae	*Asterionella*	1,459	Bacillariophyta	Fragilariaceae	*Asterionella*	10
Bacillariophyta	Fragilariaceae	*Fragilaria*	501	Bacillariophyta	Fragilariaceae	*Fragilaria*	21
Bacillariophyta	Fragilariaceae	*Tabellaria*	1,110	Bacillariophyta	Fragilariaceae	*Synedra*	3
Chrysophyta	Dinobryaceae	*Dinobryon*	21	Bacillariophyta	Fragilariaceae	*Tabellaria*	174
	August 18, 1999			Chrysophyta	Dinobryaceae	*Dinobryon*	14
Bacillariophyta	Coscinodiscaceae	*Melosira*	3	Cyanophyta	Nostocaceae	*Anabaena*	3
Bacillariophyta	Coscinodiscaceae	*Stephanodiscus*	3	Cyanophyta	Nostocaceae	*Aphanizomenon*	707
Bacillariophyta	Fragilariaceae	*Tabellaria*	3	Pyrrophyta	Ceratiaceae	*Ceratium*	7
Cyanophyta	Nostocaceae	*Anabaena*	7		**November 30, 1999**		
Cyanophyta	Nostocaceae	*Aphanizomenon*	7	Bacillariophyta	Coscinodiscaceae	*Melosira*	4,466
Pyrrophyta	Ceratiaceae	*Ceratium*	3	Bacillariophyta	Fragilariaceae	*Asterionella*	42
				Bacillariophyta	Fragilariaceae	*Fragilaria*	17
				Bacillariophyta	Fragilariaceae	*Tabellaria*	769
				Bacillariophyta	Naviculaceae	*Navicula*	7
				Chlorophyta	Hydrodictyaceae	*Pandorina*	3

Table 27. Number of phytoplankton detected in Blue Mesa Reservoir, April–November 1999—Continued

[Algal units/L, algal units per liter; site number refers to table 1 and figure 1]

Phylum	Family	Genus	Algal units/L
BLUE MESA RESERVOIR AT SAPINERO BASIN (SITE BM3)			
	April 20, 1999		
Bacillariophyta	Coscinodiscaceae	*Melosira*	877
Bacillariophyta	Fragilariaceae	*Asterionella*	1,507
Bacillariophyta	Fragilariaceae	*Fragilaria*	414
Bacillariophyta	Fragilariaceae	*Tabellaria*	376
Chrysophyta	Dinobryaceae	*Dinobryon*	3
	August 18, 1999		
Bacillariophyta	Coscinodiscaceae	*Stephanodiscus*	3
Chlorophyta	Chlorococcaceae	*Schroederia*	3
Cyanophyta	Nostocaceae	*Aphanizomenon*	24
Pyrrophyta	Ceratiaceae	*Ceratium*	3
	October 6, 1999		
Bacillariophyta	Coscinodiscaceae	*Melosira*	10
Bacillariophyta	Fragilariaceae	*Asterionella*	3
Bacillariophyta	Fragilariaceae	*Fragilaria*	21
Bacillariophyta	Fragilariaceae	*Synedra*	7
Bacillariophyta	Fragilariaceae	*Tabellaria*	63
Chlorophyta	Chlamydomonadaceae	*Chlamydomonas*	3
Chlorophyta	Hydrodictyaceae	*Pandorina*	17
Cyanophyta	Nostocaceae	*Aphanizomenon*	66
Pyrrophyta	Ceratiaceae	*Ceratium*	3
	November 30, 1999		
Bacillariophyta	Coscinodiscaceae	*Melosira*	630
Bacillariophyta	Fragilariaceae	*Asterionella*	3
Bacillariophyta	Fragilariaceae	*Tabellaria*	136
Bacillariophyta	Naviculaceae	*Navicula*	7

Table 28. Chlorophyll-*a* concentrations and trophic-state indices, Blue Mesa, Morrow Point, and Crystal Reservoirs, April–December 1999

[mg/m^3, milligrams per cubic meter; TP, total phosphorus; CH*a*, chlorophyll-*a*; SD, Secchi depth; site number refers to table 1 and figure 1; --, no data]

Date	Chlorophyll-*a* (mg/m^3)	Trophic-state index[1]			Date	Chlorophyll-*a* (mg/m^3)	Trophic-state index[1]		
		TP	CH*a*	SD			TP	CH*a*	SD
BLUE MESA RESERVOIR AT IOLA BASIN (SITE BM1)					**MORROW POINT RESERVOIR AT KOKANEE BAY (SITE MP2)**				
04/20/99	4.56	47	45	44	04/21/99	3.17	44	42	44
08/19/99	1.52	34	35	38	08/17/99	2.47	36	40	36
10/06/99	7.55	55	50	44	10/12/99	1.45	49	34	42
11/30/99	4.56	46	45	40	12/01/99	2.37	48	39	38
BLUE MESA RESERVOIR AT CEBOLLA BASIN (SITE BM2)					**MORROW POINT RESERVOIR OFF HERMITS REST (SITE MP3)**				
04/20/99	6.98	41	50	44	04/21/99	4.39	43	45	37
08/19/99	0.86	51	29	37	08/17/99	1.68	32	36	31
10/06/99	2.12	43	38	37	10/12/99	0.91	47	30	37
11/30/99	5.75	43	48	40	12/01/99	2.38	47	39	34
BLUE MESA RESERVOIR AT SAPINERO BASIN (SITE BM3)					**CRYSTAL RESERVOIR NEAR CRYSTAL DAM (SITE CR1)**				
04/20/99	3.97	39	44	42	04/20/99	3.07	45	42	44
08/19/99	1.42	41	34	38	08/24/99	2.01	36	37	35
10/06/99	1.50	39	35	42	10/13/99	2.18	49	38	42
11/30/99	4.18	47	45	37	12/02/99	3.32	47	42	--
MORROW POINT RESERVOIR ABOVE PINE CREEK (SITE MP1)									
04/21/99	3.14	48	42	47					
08/23/99	0.95	48	30	45					
10/12/99	1.26	49	33	40					
12/01/99	3.69	47	43	40					

[1]Calculation of trophic-state indices (from Carlson, 1977):

TP = 10×[6–{ln(48/total phosphorus concentration in mg/m^3)/ln2}]

CH*a* = 10×(6–[{2.04–(0.68×ln chlorophyll-*a* concentration)}/ln2])

SD = 10×[6–(ln Secchi depth/ln2)]

Table 29. Physical properties and suspended sediment (inflows only) for Blue Mesa Reservoir inflow and outflow sites, May–December 1999

[ft^3/s, cubic feet per second; C, Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; site number refers to table 1 and figure 1; --, no data]

Date	Time	Discharge (ft^3/s)	Width (feet)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Suspended sediment (mg/L)
GUNNISON RIVER AT COUNTY ROAD 32 BELOW GUNNISON (SITE BI1)								
05/26/99	0845	2,920	154	7.6	8.8	8.0	191	80
08/25/99	0810	974	140	13.3	7.7	7.9	212	10
10/21/99	1100	544	112	3.9	10.6	8.0	214	0.9
12/06/99	1500	330	105	0.0	11.3	8.5	241	5
BEAVER CREEK AT HIGHWAY 50, NEAR GUNNISON (SITE BI2)								
06/01/99	1600	62.0	25.0	13.0	7.6	7.8	74	6
08/12/99	1350	24.5	25.5	15.2	7.5	7.7	67	5
10/04/99	1550	5.24	10.7	10.0	8.3	7.8	93	1
12/06/99	1115	2.68	8.0	0.0	11.0	7.7	98	1
STEUBEN CREEK AT HIGHWAY 50, NEAR GUNNISON (SITE BI3)								
05/27/99	1600	40.0	15.5	7.8	9.3	7.4	59	8
08/11/99	1340	12.8	15.0	12.5	8.0	7.6	57	4
10/04/99	1430	3.13	10.3	6.5	9.2	7.6	81	1
11/30/99	1535	2.40	10.0	0.0	11.2	7.9	83	2
EAST ELK CREEK ABOVE HIGHWAY 50, NEAR SAPINERO (SITE BI4)								
05/26/99	1500	29.0	10.5	10.0	8.6	7.6	62	12
08/12/99	1130	4.70	10.1	13.5	7.7	8.0	98	12
10/05/99	0825	2.30	11.8	5.0	9.8	7.6	111	2
11/29/99	1515	3.02	8.1	0.1	10.8	8.0	91	15
RED CREEK ABOVE HIGHWAY 50, NEAR SAPINERO (SITE BI5)								
05/26/99	1300	10.0	5.5	9.0	8.8	7.9	73	13
08/09/99	1320	0.77	2.0	16.5	6.9	7.8	159	10
10/04/99	1220	0.76	3.3	8.3	8.9	8.0	171	5
12/06/99	1300	1.10	5.1	0.2	10.8	7.8	135	6
WEST ELK CREEK ABOVE BLUE MESA RESERVOIR, NEAR SAPINERO (SITE BI6)								
06/02/99	0935	89.0	26.0	5.5	9.6	7.5	54	9
08/18/99	0925	14.0	17.0	9.1	8.9	7.8	73	10
10/06/99	1430	4.84	15.6	9.4	8.4	8.2	85	0.9
11/30/99	1230	5.19	12.0	–0.4	10.9	7.5	81	3
SOAP CREEK ABOVE BLUE MESA RESERVOIR, NEAR SAPINERO (SITE BI7)								
05/25/99	1530	269	29	9.5	8.7	7.8	70	72
08/12/99	0845	23.0	28.0	10.3	8.6	8.0	120	7
10/05/99	1040	12.0	25.4	2.8	10.4	8.3	125	2
12/07/99	1440	15.2	24.5	0.0	11.0	7.8	131	2
SOUTH WILLOW CREEK ABOVE HIGHWAY 149, NEAR GUNNISON (SITE BI8)								
06/01/99	1230	3.40	7.5	12.2	7.7	8.3	409	1

Table 29. Physical properties and suspended sediment (inflows only) for Blue Mesa Reservoir inflow and outflow sites, May–December 1999—Continued

[ft^3/s, cubic feet per second; C, Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; site number refers to table 1 and figure 1; --, no data]

Date	Time	Discharge (ft^3/s)	Width (feet)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Suspended sediment (mg/L)
CEBOLLA CREEK AT BRIDGE SOUTHEAST OF POWDERHORN (SITE BI9)								
06/01/99	0845	468	34.0	5.5	9.4	7.6	81	93
08/11/99	1030	285	36.0	10.0	8.6	7.6	114	23
10/11/99	1250	70	34.0	7.5	9.4	7.9	111	3
12/08/99	0915	36	30.0	0.0	10.8	7.8	133	3
LAKE FORK OF THE GUNNISON RIVER BELOW GATEVIEW (SITE BI10)								
05/31/99	1230	1,050	[1]24	9.0	8.9	7.6	115	90
08/18/99	1330	481	101	13.5	8.2	8.0	134	7
10/11/99	1505	137	67.0	10.5	8.5	8.1	158	3
12/08/99	1145	64	49.0	0.0	--	8.0	182	4
BLUE MESA RESERVOIR DISCHARGE AT BLUE MESA POWERHOUSE, NEAR SAPINERO (SITE BO)								
06/02/99	1215	[2]1,836	--	6.5	--	8.1	200	--
08/16/99	1500	[2]2,436	--	9.1	8.0	7.7	174	--
10/05/99	1355	[2]3,263	--	12.5	7.6	7.6	176	--
12/08/99	1415	[2]1,317	--	6.0	--	8.0	190	--

[1]Width at bridge.
[2]Outflow from Blue Mesa Reservoir. Value is mean value for the day.

Table 30. Nitrogen and phosphorus concentrations in Blue Mesa Reservoir inflow and outflow sites, May–December 1999

[Site number refers to table 1 and figure 1; <, less than; E, estimated]

Date	Time	Concentration, in milligrams per liter: Nitrogen, ammonia, dissolved	Nitrogen, un-ionized ammonia, dissolved[1]	Nitrogen, nitrite, dissolved	Nitrogen, nitrate + nitrite, dissolved	Nitrogen, nitrate, dissolved[2]	Nitrogen, inorganic, dissolved[3]	Nitrogen, ammonia + organic, dissolved	Nitrogen, ammonia + organic, total	Nitrogen, total[4]	Ortho-phosphate, dissolved	Phos-phorus, dissolved	Phos-phorus, total
GUNNISON RIVER AT COUNTY ROAD 32 BELOW GUNNISON (SITE BI1)													
05/26/99	0845	0.006	<0.001	0.001	0.047	0.046	0.053	0.2	0.5	0.5	0.01	0.014	0.091
08/25/99	0810	0.006	<0.001	0.001	0.035	0.034	0.041	0.2	0.2	0.2	0.018	0.021	0.044
10/21/99	1100	<0.002	<0.001	0.002	0.014	0.012	0.014	0.1	0.2	0.2	0.007	0.016	0.022
12/06/99	1500	<0.002	<0.001	0.001	0.047	0.046	0.047	E 0.06	0.1	0.1	0.011	0.019	0.039
BEAVER CREEK AT HIGHWAY 50, NEAR GUNNISON (SITE BI2)													
06/01/99	1600	0.007	<0.001	<0.001	<0.005	<0.005	0.007	0.2	0.2	0.2	0.048	0.051	0.07
08/12/99	1350	0.005	<0.001	0.001	<0.005	<0.005	0.006	[5]0.2	[5]<0.1	[5]<0.1	0.057	0.06	0.072
10/04/99	1550	<0.002	<0.001	<0.001	<0.005	<0.005	<0.005	0.1	0.1	0.1	0.053	0.058	0.093
12/06/99	1115	<0.002	<0.001	<0.001	<0.005	<0.005	<0.005	[5]E 0.09	[5]E 0.06	[5]E 0.06	0.032	0.043	0.056
STEUBEN CREEK AT HIGHWAY 50, NEAR GUNNISON (SITE BI3)													
05/27/99	1600	0.006	<0.001	<0.001	0.008	0.008	0.014	0.2	0.3	0.3	0.037	0.043	0.062
08/11/99	1340	0.006	<0.001	0.001	<0.005	<0.005	0.007	[5]E 0.09	[5]E 0.08	[5]E 0.08	0.04	0.044	0.057
10/04/99	1430	<0.002	<0.001	<0.001	<0.005	<0.005	<0.005	0.1	0.2	0.2	0.057	0.065	0.074
11/30/99	1535	<0.002	<0.001	<0.001	0.006	0.006	0.006	[5]<0.1	[5]E 0.07	[5]E 0.08	0.026	0.032	0.035
EAST ELK CREEK ABOVE HIGHWAY 50, NEAR SAPINERO (SITE BI4)													
05/26/99	1500	0.004	<0.001	0.001	0.008	0.007	0.012	0.2	0.3	0.3	0.071	0.078	0.11
08/12/99	1130	0.006	<0.001	0.002	0.008	0.006	0.014	[5]0.1	[5]<0.1	[5]<0.1	0.14	0.15	0.2
10/05/99	0825	<0.002	<0.001	<0.001	<0.005	<0.005	<0.005	0.1	0.2	0.2	0.12	0.13	0.18
11/29/99	1515	<0.002	<0.001	<0.001	0.005	0.005	0.005	[5]<0.1	[5]E 0.06	[5]E 0.06	0.089	0.1	0.13
RED CREEK ABOVE HIGHWAY 50, NEAR SAPINERO (SITE BI5)													
05/26/99	1300	0.004	<0.001	0.001	0.008	0.007	0.012	0.2	0.3	0.3	0.06	0.069	0.11
08/09/99	1320	0.014	<0.001	0.002	0.015	0.013	0.029	0.2	0.3	0.3	0.12	0.13	0.2
10/04/99	1220	<0.002	<0.001	<0.001	<0.005	<0.005	<0.005	0.2	0.2	0.2	0.082	0.093	0.2
12/06/99	1300	0.003	<0.001	0.001	0.006	0.005	0.009	[5]0.1	[5]E 0.08	[5]E 0.08	0.063	0.081	0.15
WEST ELK CREEK ABOVE BLUE MESA RESERVOIR, NEAR SAPINERO (SITE BI6)													
06/02/99	0935	0.008	<0.001	<0.001	<0.005	<0.005	0.008	0.1	0.1	0.1	0.029	0.029	0.046
08/18/99	0925	0.002	<0.001	0.001	0.007	0.006	0.009	E 0.09	0.1	0.1	0.048	0.053	0.068
10/06/99	1430	<0.002	<0.001	<0.001	<0.005	<0.005	<0.005	E 0.09	0.1	0.1	0.058	0.062	0.068
11/30/99	1230	<0.002	<0.001	<0.001	0.017	0.017	0.017	[5]<0.1	[5]E 0.05	[5]E 0.07	0.06	0.067	0.075

Table 30. Nitrogen and phosphorus concentrations in Blue Mesa Reservoir inflow and outflow sites, May–December 1999—Continued

[Site number refers to table 1 and figure 1; <, less than; E, estimated]

Date	Time	Concentration, in milligrams per liter											
		Nitrogen, ammonia, dissolved	Nitrogen, un-ionized ammonia, dissolved[1]	Nitrogen, nitrite, dissolved	Nitrogen, nitrate + nitrite, dissolved	Nitrogen, nitrate, dissolved[2]	Nitrogen, inorganic, dissolved[3]	Nitrogen, ammonia + organic, dissolved	Nitrogen, ammonia + organic, total	Nitrogen, total[4]	Ortho-phosphate, dissolved	Phos-phorus, dissolved	Phos-phorus, total
SOAP CREEK ABOVE BLUE MESA RESERVOIR, NEAR SAPINERO (SITE BI7)													
05/25/99	1530	0.003	<0.001	0.001	0.01	0.099	0.01	0.2	0.3	0.3	0.016	0.019	0.089
08/12/99	0845	<0.002	<0.001	0.001	<0.005	<0.005	<0.005	[5]E 0.08	[5]E 0.05	[5]E 0.05	0.019	0.019	0.034
10/05/99	1040	<0.002	<0.001	<0.001	<0.005	<0.005	<0.005	0.1	0.1	0.1	0.018	0.022	0.026
12/07/99	1440	<0.002	<0.001	<0.001	<0.005	<0.005	<0.005	<0.1	<0.1	<0.1	0.024	0.031	0.036
SOUTH WILLOW CREEK ABOVE HIGHWAY 149, NEAR GUNNISON (SITE BI8)													
06/01/99	1230	0.011	<0.001	<0.001	<0.005	<0.005	0.011	0.4	0.4	0.4	0.066	0.07	0.077
CEBOLLA CREEK AT BRIDGE SOUTHEAST OF POWDERHORN (SITE BI9)													
06/01/99	0845	0.007	<0.001	0.001	0.021	0.020	0.028	0.2	0.4	0.4	0.033	0.037	0.15
08/11/99	1030	0.012	<0.001	0.001	0.025	0.024	0.037	[5]0.2	[5]E 0.09	[5]E 0.1	0.033	0.037	0.1
10/11/99	1250	<0.002	<0.001	<0.001	<0.005	<0.005	<0.005	0.1	0.1	0.1	0.033	0.044	0.058
12/08/99	0915	0.002	<0.001	0.001	0.083	0.082	0.085	E 0.07	0.1	0.2	0.038	0.055	0.062
LAKE FORK OF THE GUNNISON RIVER BELOW GATEVIEW (SITE BI10)													
05/31/99	1230	<0.002	<0.001	0.001	0.031	0.030	0.031	E 0.1	0.2	0.2	0.004	0.006	0.056
08/18/99	1330	0.005	<0.001	0.001	<0.005	<0.005	0.006	[5]0.1	[5]E 0.08	[5]E 0.08	0.008	0.015	0.022
10/11/99	1505	0.006	<0.001	0.001	<0.005	<0.005	0.007	[5]E 0.1	[5]E 0.08	[5]E 0.08	0.01	0.013	0.022
12/08/99	1145	0.009	<0.001	0.001	0.079	0.078	0.088	[6]<0.1	[6]E 0.07	E 0.1	0.014	0.025	0.03
BLUE MESA RESERVOIR DISCHARGE AT BLUE MESA POWERHOUSE, NEAR SAPINERO (SITE BO)													
06/02/99	1215	0.007	<0.001	0.001	0.005	0.004	0.012	[5]0.2	[5]0.1	[5]0.1	0.005	0.006	0.014
08/16/99	1500	<0.002	<0.001	0.001	0.054	0.053	0.054	[5]0.1	[5]E 0.09	[5]E 0.1	0.014	0.018	0.019
10/05/99	1355	<0.002	<0.001	0.001	0.048	0.047	0.048	[5]0.2	[5]0.1	[5]0.1	0.014	0.017	0.021
12/08/99	1415	<0.002	<0.001	<0.001	0.036	0.036	0.036	E 0.09	0.1	0.1	0.01	0.018	0.021

[1]Calculated from the ammonia concentrations and pH, temperature, and an equilibrium constant (U.S. Geological Survey Office of Water Quality Technical Memorandum No. 93.12, 1993, URL http://water.usgs.gov/admin/memo/QW/qw93.12.html, accessed February 7, 2002).

[2]Nitrate plus nitrite minus nitrite.

[3]Calculated as the sum of dissolved ammonia and dissolved nitrate plus nitrite. See table 4.

[4]Calculated as the sum of total ammonia plus organic nitrogen and dissolved nitrate plus nitrite. See table 4.

[5]Based on variability in the laboratory method, there is no significant difference between the concentration of (1) dissolved ammonia plus organic nitrogen, (2) total ammonia plus organic nitrogen, and (3) total nitrogen (D.K. Mueller, U.S. Geological Survey, oral commun., 2002).

[6]Based on variability in the laboratory method, there is no significant difference between the concentration of (1) dissolved ammonia plus organic nitrogen and (2) total ammonia plus organic nitrogen (D.K. Mueller, U.S. Geological Survey, oral commun., 2002).

Table 31. Reservoir profile measurements, Morrow Point Reservoir above Pine Creek (site MP1), April–December 1999

[Site number refers to table 1 and figure 1; C, Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)
APRIL 21, 1999, SECCHI-DISC DEPTH, 2.5 METERS					**OCTOBER 12, 1999, SECCHI-DISC DEPTH, 4.0 METERS**				
1	4.4	10.5	8.2	212	1	11.7	7.1	7.3	183
2	4.4	10.4	8.2	211	2	11.7	7.0	7.3	182
3	4.4	10.4	8.2	210	3	11.7	7.0	7.3	183
4	4.4	10.5	8.2	211	4	11.5	7.0	7.4	183
5	4.4	10.5	8.2	210	5	11.4	7.0	7.4	184
6	4.4	10.5	8.3	211	6	11.4	7.0	7.4	184
7	4.4	10.5	8.3	209	7	11.4	7.0	7.3	184
8	4.4	10.5	8.3	209	8	11.3	6.9	7.3	184
9	4.4	10.5	8.3	210	9	11.3	7.0	7.3	184
					9.5	11.3	7.0	7.3	184
AUGUST 23, 1999, SECCHI-DISC DEPTH, 2.9 METERS					**DECEMBER 1, 1999, SECCHI-DISC DEPTH, 4.0 METERS**				
1	10.0	7.6	7.6	172	1	7.7	8.1	7.2	187
2	10.0	7.6	7.6	172	2	7.7	8.1	7.3	187
3	10.0	7.6	7.6	173	3	7.7	8.2	7.3	187
4	10.0	7.5	7.6	170	4	7.7	8.2	7.3	187
5	9.9	7.6	7.6	171	5	7.7	8.2	7.4	187
6	9.9	7.6	7.6	173	6	7.7	8.1	7.4	187
7	10.0	7.5	7.6	174	7	7.7	8.1	7.4	187
8	10.0	7.5	7.6	170	8	7.7	8.1	7.4	187
9	9.9	7.5	7.6	174	9	7.7	8.0	7.4	187
10	9.9	7.5	7.6	173	10	7.7	7.9	7.4	187
11	9.9	7.5	7.6	172	11	7.7	7.9	7.4	187
12	9.9	7.5	7.6	173	12	7.7	7.9	7.4	187
12.6	9.9	7.4	7.6	175	12.5	7.7	7.8	7.4	187

Table 32. Reservoir profile measurements, Morrow Point Reservoir at Kokanee Bay (site MP2), April–December 1999

[Site number refers to table 1 and figure 1; C, Celsius; mg/L, milligrams per liter; μS/cm, microsiemens per centimeter at 25 degrees Celsius; --, no data]

Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (μS/cm)	Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (μS/cm)
APRIL 21, 1999, SECCHI-DISC DEPTH, 3.0 METERS					**AUGUST 17, 1999, SECCHI-DISC DEPTH, 5.3 METERS**				
1	5.3	10.2	8.2	205	1	15.8	--	8.2	168
2	5.2	10.3	8.2	206	2	15.1	--	8.2	168
3	5.1	10.2	8.3	204	3	14.2	--	8.2	168
4	5.0	10.2	8.2	205	4	12.5	--	8.0	166
5	5.0	10.2	8.2	205	5	11.4	--	7.9	166
6	5.0	10.2	8.2	207	6	10.8	--	7.8	168
7	5.0	10.2	8.2	205	7	10.5	--	7.8	168
8	5.0	10.2	8.2	206	8	10.2	--	7.7	169
9	5.0	10.1	8.2	204	9	10.0	--	7.7	170
10	4.9	10.1	8.2	204	10	9.9	--	7.7	170
11	4.9	10.1	8.2	205	11	9.8	--	7.7	172
12	4.9	10.1	8.2	204	12	9.8	--	7.7	171
13	4.9	10.1	8.2	205	13	9.7	--	7.7	173
14	4.9	10.2	8.2	204	14	9.6	--	7.7	172
15	4.9	10.2	8.2	204	15	9.6	--	7.7	173
16	4.9	10.1	8.2	204	16	9.6	--	7.7	172
17	4.9	10.1	8.2	204	17	9.5	--	7.7	172
18	5.0	10.1	8.2	204	18	9.5	--	7.7	173
19	4.9	10.2	8.2	204	19	9.5	--	7.7	171
20	5.0	10.1	8.2	204	20	9.4	--	7.6	171
25	4.8	10.4	8.2	204	25	9.3	--	7.6	174
30	4.6	10.5	8.2	207	30	8.9	--	7.6	177
35	4.6	10.4	8.2	206					
38.2	4.6	10.3	8.2	204					

Table 32. Reservoir profile measurements, Morrow Point Reservoir at Kokanee Bay (site MP2), April–December 1999—Continued

[Site number refers to table 1 and figure 1; C, Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, no data]

Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)
OCTOBER 12, 1999, SECCHI-DISC DEPTH, 3.5 METERS					**DECEMBER 1, 1999, SECCHI-DISC DEPTH, 4.5 METERS**				
1	11.7	6.6	7.5	181	1	7.0	8.2	7.4	184
2	11.8	6.6	7.5	181	2	7.0	8.2	7.4	184
3	11.7	6.6	7.5	181	3	7.0	8.1	7.4	184
4	11.7	6.6	7.5	180	4	7.0	8.1	7.3	184
5	11.7	6.6	7.4	180	5	7.0	8.1	7.3	184
6	11.7	6.6	7.4	180	6	7.0	8.1	7.4	184
7	11.7	6.5	7.4	180	7	7.1	8.1	7.4	184
8	11.7	6.5	7.4	180	8	7.0	8.0	7.4	184
9	11.7	6.5	7.4	180	9	7.0	8.0	7.4	184
10	11.7	6.5	7.4	180	10	7.0	8.1	7.4	184
11	11.7	6.5	7.4	180	11	7.0	8.0	7.4	184
12	11.7	6.5	7.4	180	12	7.0	8.0	7.4	184
13	11.7	6.6	7.4	180	13	7.0	8.0	7.4	184
14	11.7	6.5	7.4	180	14	7.0	8.0	7.4	185
15	11.7	6.6	7.4	180	15	7.0	8.0	7.4	185
16	11.6	6.5	7.4	180	16	7.0	8.0	7.4	184
17	11.5	6.5	7.4	179	17	7.0	8.0	7.4	184
18	11.5	6.5	7.4	179	18	7.0	8.0	7.4	185
19	11.4	6.5	7.4	178	19	7.0	8.0	7.4	184
20	11.1	6.5	7.4	176	20	7.0	7.9	7.4	184
25	10.9	6.4	7.4	176	25	7.0	8.0	7.4	185
30	7.9	5.6	7.2	185	30	7.0	7.9	7.4	184
35	6.1	6.0	7.2	190	35	6.6	7.1	7.2	184
40	5.9	6.2	7.2	191	38.9	6.4	3.2	7.1	193
45	5.8	6.2	7.2	191					
50	5.8	6.2	7.2	192					
53.2	5.8	3.5	7.0	209					

Table 33. Reservoir profile measurements, Morrow Point Reservoir off Hermits Rest (site MP3), April–December 1999

[Site number refers to table 1 and figure 1; C, Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, no data]

Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)
APRIL 21, 1999, SECCHI-DISC DEPTH, 5.0 METERS					**AUGUST 17, 1999, SECCHI-DISC DEPTH, 7.3 METERS**				
1	4.8	10.1	8.2	205	1	15.2	--	8.5	170
2	4.6	10.2	8.2	203	2	15.2	--	8.3	170
3	4.5	10.1	8.2	204	3	14.9	--	8.3	170
4	4.5	10.1	8.2	204	4	14.5	--	8.3	170
5	4.5	10.1	8.2	203	5	13.7	--	8.2	169
6	4.5	10.0	8.2	204	6	13.4	--	8.2	169
7	4.5	10.0	8.2	202	7	11.4	--	8.0	171
8	4.5	10.0	8.2	203	8	10.4	--	7.9	172
9	4.5	10.0	8.2	204	9	10.1	--	7.8	173
10	4.5	10.0	8.2	205	10	10.0	--	7.8	173
11	4.4	10.0	8.2	203	11	9.9	--	7.8	173
12	4.4	9.9	8.2	205	12	9.7	--	7.8	173
13	4.4	9.9	8.2	204	13	9.7	--	7.8	172
14	4.4	9.9	8.2	203	14	9.7	--	7.7	172
15	4.4	9.9	8.2	202	15	9.7	--	7.7	174
16	4.4	9.9	8.2	204	16	9.6	--	7.7	172
17	4.4	9.9	8.2	202	17	9.5	--	7.7	173
18	4.4	9.9	8.2	204	18	9.4	--	7.7	173
19	4.3	9.9	8.2	203	19	9.4	--	7.7	173
20	4.3	9.9	8.2	204	20	9.4	--	7.7	174
25	4.3	9.8	8.2	203	25	9.3	--	7.7	173
30	4.3	9.8	8.2	201	30	9.0	--	7.7	175
35	4.2	9.8	8.2	202	35	7.1	--	7.7	183
40	4.2	9.8	8.2	202	40	5.8	--	7.7	186
45	4.2	9.7	8.2	201	45	5.6	--	7.7	187
50	4.1	9.7	8.2	202	50	5.5	--	7.7	186
55	4.1	9.7	8.2	201	55	5.4	--	7.7	185
60	4.0	9.7	8.1	200	60	5.2	--	7.8	186
65	3.9	9.7	8.1	201	65	5.0	--	7.8	185
70	4.0	9.7	8.1	200	69.5	4.9	--	7.8	186
73	4.0	9.6	8.1	201					

Table 33. Reservoir profile measurements, Morrow Point Reservoir off Hermits Rest (site MP3), April–December 1999—Continued

[Site number refers to table 1 and figure 1; C, Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, no data]

Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)
OCTOBER 12, 1999, SECCHI-DISC DEPTH, 5.0 METERS					DECEMBER 1, 1999, SECCHI-DISC DEPTH, 6.0 METERS				
1	11.7	6.9	7.5	179	1	6.6	8.1	7.4	181
2	11.6	6.9	7.5	179	2	6.6	8.1	7.4	181
3	11.6	6.9	7.5	179	3	6.6	8.0	7.4	181
4	11.6	6.9	7.5	179	4	6.6	8.1	7.4	181
5	11.6	6.9	7.5	179	5	6.6	8.1	7.4	181
6	11.6	6.8	7.5	179	6	6.6	8.1	7.4	181
7	11.6	6.8	7.5	179	7	6.6	8.1	7.4	181
8	11.6	6.9	7.5	179	8	6.6	8.0	7.4	181
9	11.6	6.9	7.5	179	9	6.6	8.0	7.4	181
10	11.5	6.8	7.5	179	10	6.6	8.0	7.4	181
11	11.5	6.8	7.5	179	11	6.6	8.0	7.4	181
12	11.5	6.8	7.5	179	12	6.6	8.0	7.4	181
13	11.5	6.8	7.5	179	13	6.6	8.0	7.4	181
14	11.5	6.8	7.5	179	14	6.6	8.0	7.4	181
15	11.5	6.8	7.5	179	15	6.6	8.0	7.4	181
16	11.5	6.8	7.5	179	16	6.6	8.0	7.4	181
17	11.5	6.8	7.5	179	17	6.6	8.0	7.4	181
18	11.5	6.8	7.5	179	18	6.6	8.0	7.4	181
19	11.5	6.8	7.5	179	19	6.6	7.9	7.4	181
20	11.5	6.8	7.5	179	20	6.6	8.0	7.4	181
25	11.5	6.8	7.5	179	25	6.6	8.0	7.4	181
30	11.3	6.7	7.5	178	30	6.6	7.9	7.4	181
35	6.7	6.9	7.4	188	35	6.6	7.9	7.5	181
40	5.9	6.9	7.3	190	40	6.6	7.9	7.5	181
45	5.8	7.0	7.3	190	45	6.6	7.9	7.5	181
50	5.8	7.0	7.3	190	50	6.6	7.8	7.5	181
55	5.7	7.3	7.3	190	55	6.6	7.9	7.5	181
60	5.5	7.5	7.3	191	60	6.6	7.8	7.5	181
65	5.4	7.6	7.4	191	65	5.7	6.8	7.2	186
70	5.1	7.8	7.4	191	70	5.5	7.0	7.2	187
73.5	5.0	7.9	7.4	191	75	5.3	7.0	7.2	187
					80	5.0	6.7	7.2	189
					85	4.8	6.5	7.2	190
					90	4.8	6.2	7.2	190
					95	4.7	5.6	7.2	191
					99.8	4.7	5.5	7.0	192

Table 34. Nitrogen and phosphorus concentrations in Morrow Point Reservoir, April–December 1999

[Site number refers to table 1 and figure 1; <, less than; E, estimated; --, no data]

Date	Time	Sampling depth (feet)	Concentration, in milligrams per liter											
			Nitrogen, ammonia, dissolved	Nitrogen, un-ionized ammonia, dissolved[1]	Nitrogen, nitrite, dissolved	Nitrogen, nitrate + nitrite, dissolved	Nitrogen, nitrate, dissolved[2]	Nitrogen, inorganic, dissolved[3]	Nitrogen, ammonia + organic, dissolved	Nitrogen, ammonia + organic, total	Nitrogen, total[4]	Ortho-phosphate, dissolved	Phos-phorus, dissolved	Phos-phorus, total
MORROW POINT RESERVOIR ABOVE PINE CREEK (SITE MP1)														
04/21/99	1155	2	0.004	<0.001	0.001	0.08	0.079	0.08	0.1	0.2	0.3	0.005	0.008	0.021
08/23/99	1445	2	0.01	<0.001	0.001	0.056	0.055	0.07	0.2	0.2	0.3	0.014	0.018	0.021
	1500	43	0.095	<0.001	0.001	0.054	0.053	0.149	0.2	0.2	0.3	0.013	0.018	0.019
10/12/99	0940	2	0.007	<0.001	0.001	0.042	0.041	0.049	0.1	0.1	0.1	0.015	0.019	0.022
	1000	31	0.005	<0.001	0.001	0.048	0.047	0.053	0.1	0.1	0.1	0.018	0.019	0.024
12/01/99	0940	2	<0.002	<0.001	<0.001	0.032	0.032	0.032	E 0.09	0.1	0.1	0.008	0.014	0.02
	0950	46	<0.002	<0.001	<0.001	0.032	0.032	0.032	E 0.07	0.1	0.1	0.008	0.014	0.02
MORROW POINT RESERVOIR AT KOKANEE BAY (SITE MP2)														
04/21/99	1055	2	0.003	<0.001	0.001	0.08	0.079	0.08	0.2	0.2	0.3	0.005	0.007	0.016
	1125	60	0.004	<0.001	<0.001	0.08	0.08	0.08	0.1	0.2	0.3	0.005	0.007	0.016
08/17/99	1335	3	0.004	<0.001	<0.001	<0.005	<0.005	<0.005	0.1	0.1	0.1	0.002	0.008	0.009
	1425	14	0.002	<0.001	<0.001	<0.005	<0.005	<0.005	0.1	0.3	0.3	0.004	0.009	0.014
	1440	100	0.002	<0.001	<0.001	0.04	0.04	0.04	[5]0.2	[5]0.1	[5]0.1	0.014	0.019	0.019
10/12/99	1045	2	0.005	<0.001	0.002	0.037	0.035	0.042	0.1	0.1	0.1	0.016	0.017	0.022
	1055	138	0.011	<0.001	0.001	0.072	0.071	0.083	0.1	0.1	0.2	0.018	0.018	0.023
12/01/99	1030	2	<0.002	<0.001	<0.001	0.039	0.039	0.039	E 0.07	0.1	0.1	0.009	0.015	0.021
	1040	16	<0.002	<0.001	<0.001	0.038	0.038	0.038	<0.1	0.1	0.1	0.01	0.019	0.021
	1050	146	<0.002	<0.001	<0.001	0.067	0.067	0.067	<0.1	E 0.09	E 0.2	0.013	0.019	0.022
MORROW POINT RESERVOIR OFF HERMITS REST (SITE MP3)														
04/21/99	0925	2	0.002	<0.001	0.001	0.09	0.089	0.09	0.1	0.1	0.2	0.007	0.009	0.015
	1000	150	0.003	<0.001	0.001	0.09	0.089	0.09	0.1	0.1	0.2	0.007	0.009	0.016
08/17/99	0900	2	<0.002	<0.001	<0.001	<0.005	<0.005	<0.005	0.1	0.1	0.1	<0.001	0.007	0.007
	1115	21.5	<0.002	<0.001	<0.001	<0.005	<0.005	<0.005	0.1	0.2	0.2	0.003	0.008	0.009
	1215	280	<0.002	<0.001	0.001	0.043	0.042	0.043	[5]0.2	[5]0.1	[5]0.1	0.01	0.014	0.012
10/12/99	1220	2	0.017	<0.001	0.001	0.037	0.036	0.054	0.1	0.1	0.1	0.016	0.015	0.02
	1235	344	--	--	--	--		--	--	--	--	--	--	--
12/01/99	1200	2	<0.002	<0.001	<0.001	0.045	0.045	0.045	E 0.05	0.1	0.1	0.01	0.016	0.019
	1210	16	<0.002	<0.001	<0.001	0.043	0.043	0.043	E 0.09	0.1	0.1	0.01	0.015	0.02
	1225	346	0.021	<0.001	<0.001	0.037	0.037	0.058	E 0.07	0.1	0.1	<0.001	0.014	0.02

[1]Calculated from the ammonia concentrations and pH, temperature, and an equilibrium constant (U.S. Geological Survey Office of Water Quality Technical Memorandum No. 93.12, 1993, URL http://water.usgs.gov/admin/memo/QW/qw93.12.html, accessed February 7, 2002).

[2]Nitrate plus nitrite minus nitrite.

[3]Calculated as the sum of dissolved ammonia and dissolved nitrate plus nitrite. See table 4.

[4]Calculated as the sum of total ammonia plus organic nitrogen and dissolved nitrate plus nitrite. See table 4.

[5]Based on variability in the laboratory method, there is no significant difference between the concentration of (1) dissolved ammonia plus organic nitrogen, (2) total ammonia plus organic nitrogen, and (3) total nitrogen (D.K. Mueller, U.S. Geological Survey, oral commun., 2002).

Table 35. Number of phytoplankton detected in Morrow Point Reservoir, April–December 1999

[Algal units/L, algal units per liter; site number refers to table 1 and figure 1]

Phylum	Family	Genus	Algal units/L	Phylum	Family	Genus	Algal units/L
			MORROW POINT RESERVOIR ABOVE PINE CREEK (SITE MP1)				
		April 21, 1999				**October 7, 1999**	
Bacillariophyta	Coscinodiscaceae	*Melosira*	167	Bacillariophyta	Coscinodiscaceae	*Melosira*	5
Bacillariophyta	Coscinodiscaceae	*Stephanodiscus*	3	Bacillariophyta	Coscinodiscaceae	*Stephanodiscus*	3
Bacillariophyta	Fragilariaceae	*Asterionella*	150	Bacillariophyta	Fragilariaceae	*Tabellaria*	13
Bacillariophyta	Fragilariaceae	*Fragilaria*	66	Bacillariophyta	Naviculaceae	*Navicula*	5
Bacillariophyta	Fragilariaceae	*Tabellaria*	77	Cyanophyta	Nostocaceae	*Aphanizomenon*	3
Bacillariophyta	Naviculaceae	*Navicula*	14			**December 1, 1999**	
		August 17, 1999		Bacillariophyta	Coscinodiscaceae	*Melosira*	432
Bacillariophyta	Coscinodiscaceae	*Melosira*	16	Bacillariophyta	Fragilariaceae	*Asterionella*	7
Bacillariophyta	Fragilariaceae	*Fragilaria*	3	Bacillariophyta	Fragilariaceae	*Fragilaria*	7
				Bacillariophyta	Fragilariaceae	*Tabellaria*	80
			MORROW POINT RESERVOIR AT KOKANEE BAY (SITE MP2)				
		April 21, 1999				**October 7, 1999**	
Bacillariophyta	Coscinodiscaceae	*Melosira*	345	Bacillariophyta	Coscinodiscaceae	*Melosira*	13
Bacillariophyta	Coscinodiscaceae	*Stephanodiscus*	10	Bacillariophyta	Fragilariaceae	*Asterionella*	3
Bacillariophyta	Fragilariaceae	*Asterionella*	209	Bacillariophyta	Fragilariaceae	*Fragilaria*	5
Bacillariophyta	Fragilariaceae	*Fragilaria*	139	Bacillariophyta	Fragilariaceae	*Tabellaria*	37
Bacillariophyta	Fragilariaceae	*Tabellaria*	146	Bacillariophyta	Naviculaceae	*Navicula*	3
Chrysophyta	Dinobryaceae	*Dinobryon*	7	Cyanophyta	Nostocaceae	*Aphanizomenon*	8
		August 17, 1999				**December 1, 1999**	
Bacillariophyta	Coscinodiscaceae	*Melosira*	3	Bacillariophyta	Coscinodiscaceae	*Melosira*	1,062
Bacillariophyta	Fragilariaceae	*Asterionella*	3	Bacillariophyta	Fragilariaceae	*Asterionella*	10
Bacillariophyta	Fragilariaceae	*Fragilaria*	10	Bacillariophyta	Fragilariaceae	*Fragilaria*	14
Bacillariophyta	Naviculaceae	*Navicula*	7	Bacillariophyta	Fragilariaceae	*Tabellaria*	178
Chlorophyta	Chlorococcaceae	*Schroederia*	3				
Chrysophyta	Dinobryaceae	*Dinobryon*	3				
			MORROW POINT RESERVOIR OFF HERMITS REST (SITE MP3)				
		April 21, 1999				**October 7, 1999**	
Bacillariophyta	Coscinodiscaceae	*Melosira*	741	Bacillariophyta	Coscinodiscaceae	*Melosira*	13
Bacillariophyta	Coscinodiscaceae	*Stephanodiscus*	7	Bacillariophyta	Fragilariaceae	*Fragilaria*	8
Bacillariophyta	Fragilariaceae	*Asterionella*	188	Bacillariophyta	Fragilariaceae	*Tabellaria*	23
Bacillariophyta	Fragilariaceae	*Fragilaria*	132	Cyanophyta	Nostocaceae	*Aphanizomenon*	13
Bacillariophyta	Fragilariaceae	*Tabellaria*	136			**December 1, 1999**	
Chlorophyta	Gamophyceae	*Spirogyra*	7	Bacillariophyta	Coscinodiscaceae	*Melosira*	278
		August 17, 1999		Bacillariophyta	Fragilariaceae	*Asterionella*	3
Bacillariophyta	Coscinodiscaceae	*Melosira*	14	Bacillariophyta	Fragilariaceae	*Fragilaria*	3
Bacillariophyta	Fragilariaceae	*Asterionella*	3	Bacillariophyta	Fragilariaceae	*Tabellaria*	45
Bacillariophyta	Fragilariaceae	*Fragilaria*	7				
Bacillariophyta	Fragilariaceae	*Tabellaria*	3				
Bacillariophyta	Naviculaceae	*Navicula*	3				

Table 36. Physical properties and suspended sediment (inflows only) for Morrow Point Reservoir inflow and outflow sites, May–December 1999

[ft^3/s, cubic feet per second; C, Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; site number refers to table 1 and figure 1; --, no data]

Date	Time	Discharge (ft^3/s)	Width (feet)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Suspended sediment (mg/L)
BLUE MESA RESERVOIR DISCHARGE AT BLUE MESA POWERHOUSE, NEAR SAPINERO (SITE BO)								
06/02/99	1215	[1]1,836	--	6.5	--	8.1	200	--
08/16/99	1500	[1]2,436	--	9.1	8.0	7.7	174	--
10/05/99	1355	[1]3,263	--	12.5	7.6	7.6	176	--
12/08/99	1415	[1]1,317	--	6.0	--	8.0	190	--
CORRAL CREEK AT HIGHWAY 92, NEAR SAPINERO (SITE MI2)								
05/25/99	0900	5.90	8.0	6.2	9.2	7.6	66	16
08/26/99	1515	0.29	2.1	15.0	7.4	7.9	96	9
10/14/99	1305	0.18	2.0	9.7	8.6	7.9	91	4
12/07/99	1245	0.38	1.4	0.0	11.0	8.0	83	10
CURECANTI CREEK NEAR SAPINERO (SITE MI3)								
05/25/99	1200	161	32.0	6.0	9.2	7.6	48	25
08/26/99	1220	16	20	17.0	7.5	8.1	100	6
10/14/99	1105	5.80	15	6.0	9.5	8.0	97	2
12/07/99	1100	6.14	13	0.0	10.3	7.8	96	3
PINE CREEK AT HIGHWAY 50, NEAR SAPINERO (SITE MI4)								
06/02/99	1420	6.30	11.0	12.5	8.0	8.2	101	19
08/10/99	1330	1.60	4.5	14.5	7.6	7.9	141	9
10/05/99	1350	1.56	6.1	8.2	8.9	8.3	137	6
12/08/99	1350	3.50	6.6	0.0	--	8.1	116	9
BLUE CREEK AT HIGHWAY 50, NEAR SAPINERO (SITE MI5)								
06/03/99	0830	148	30.5	4.0	9.6	7.6	53	31
08/10/99	1115	79.0	29.0	11.2	8.2	7.6	62	16
10/07/99	0840	24.0	26.0	5.0	9.1	7.4	73	5
12/02/99	0950	27.5	27.0	0.0	10.8	7.7	68	8
MORROW POINT RESERVOIR OUTFLOW								
05/27/99	--	[2]3,196	--	--	--	--	--	--
08/24/99	--	[2]2,135	--	--	--	--	--	--
10/07/99	--	[2]3,071	--	--	--	--	--	--
12/09/99	--	[2]1,109	--	--	--	--	--	--
MORROW POINT RESERVOIR DISCHARGE (SITE MO)								
05/27/99	0915	--	--	7.8	9.6	8.3	177	--
08/24/99	1310	--	--	9.9	8.2	7.7	175	--
10/07/99	1435	--	--	11.2	6.9	7.9	172	--
12/09/99	1150	--	--	6.0	12.0	8.1	182	--

[1]Outflow from Blue Mesa Reservoir. Value is mean value for the day.
[2]Mean value for the day.

Table 37. Nitrogen and phosphorus concentrations in Morrow Point Reservoir inflow and outflow sites, May–December 1999

[Site number refers to table 1 and figure 1; <, less than; E, estimated]

Date	Time	Concentration, in milligrams per liter											
		Nitrogen, ammonia, dissolved	Nitrogen, un-ionized ammonia, dissolved[1]	Nitrogen, nitrite, dissolved	Nitrogen, nitrate + nitrite, dissolved	Nitrogen, nitrate, dissolved[2]	Nitrogen, inorganic, dissolved[3]	Nitrogen, ammonia + organic	Nitrogen, ammonia + organic, total	Nitrogen, total[4]	Ortho-phosphate, dissolved	Phos-phorus, dissolved	Phos-phorus, total
BLUE MESA RESERVOIR DISCHARGE AT BLUE MESA POWERHOUSE, NEAR SAPINERO (SITE BO)													
06/02/99	1215	0.007	<0.001	0.001	0.005	0.004	0.012	[5]0.2	[5]0.1	[5]0.1	0.005	0.006	0.014
08/16/99	1500	<0.002	<0.001	0.001	0.054	0.053	0.054	[5]0.1	[5]E 0.09	[5]E 0.1	0.014	0.018	0.019
10/05/99	1355	<0.002	<0.001	0.001	0.048	0.047	0.048	[5]0.2	[5]0.1	[5]0.1	0.014	0.017	0.021
12/08/99	1415	<0.002	<0.001	<0.001	0.036	0.036	0.036	E 0.09	0.1	0.1	0.01	0.018	0.021
CORRAL CREEK AT HIGHWAY 92, NEAR SAPINERO (SITE MI2)													
05/25/99	0900	0.004	<0.001	<0.001	0.019	0.019	0.023	0.2	0.4	0.4	0.016	0.021	0.046
08/26/99	1515	0.004	<0.001	0.001	0.012	0.011	0.016	0.2	0.2	0.2	0.026	0.029	0.048
10/14/99	1305	0.012	<0.001	0.001	<0.005	<0.005	0.013	E 0.1	0.2	0.2	0.024	0.024	E 0.04
12/07/99	1245	<0.002	<0.001	<0.001	0.063	0.063	0.063	E 0.08	0.1	0.2	0.021	0.026	0.044
CURECANTI CREEK NEAR SAPINERO (SITE MI3)													
05/25/99	1200	0.004	<0.001	0.001	0.022	0.021	0.026	0.2	0.3	0.3	0.018	0.025	0.064
08/26/99	1220	0.01	<0.001	0.001	<0.005	<0.005	0.01	0.2	0.3	0.3	0.061	0.068	0.095
10/14/99	1105	0.005	<0.001	0.001	<0.005	<0.005	0.006	0.1	0.1	0.1	0.048	0.052	0.066
12/07/99	1100	<0.002	<0.001	0.001	0.012	0.011	0.012	E 0.06	E 0.06	E 0.07	0.027	0.038	0.054
PINE CREEK AT HIGHWAY 50, NEAR SAPINERO (SITE MI4)													
06/02/99	1420	0.009	<0.001	0.001	0.007	0.006	0.016	0.3	0.5	0.5	0.051	0.056	0.12
08/10/99	1330	0.007	<0.001	0.001	0.014	0.013	0.021	0.1	0.1	0.1	0.094	0.1	0.14
10/05/99	1350	<0.002	<0.001	<0.001	0.005	0.005	0.005	0.1	0.2	0.2	0.064	0.073	0.11
12/08/99	1350	0.005	<0.001	0.001	0.14	0.139	0.14	E 0.05	0.1	0.2	0.035	0.047	0.069
BLUE CREEK AT HIGHWAY 50, NEAR SAPINERO (SITE MI5)													
06/03/99	0830	0.009	<0.001	0.001	0.014	0.013	0.023	0.2	0.3	0.3	0.028	0.033	0.082
08/10/99	1115	0.006	<0.001	0.001	<0.005	<0.005	0.007	[5]0.1	[5]E 0.09	[5]E 0.09	0.045	0.052	0.085
10/07/99	0840	0.002	<0.001	0.001	<0.005	<0.005	<0.005	0.1	0.2	0.2	0.039	0.048	0.067
12/02/99	0950	<0.002	<0.001	<0.001	0.041	0.041	0.041	<0.1	E 0.09	E 0.1	0.034	0.044	0.062
MORROW POINT RESERVOIR DISCHARGE (SITE MO)													
05/27/99	0915	0.004	<0.001	0.001	0.01	0.009	0.01	0.1	0.2	0.2	0.006	0.007	0.034
08/24/99	1310	0.02	<0.001	0.005	0.051	0.046	0.07	0.1	0.2	0.3	0.012	0.016	0.022
10/07/99	1435	<0.002	<0.001	0.001	0.063	0.062	0.063	0.1	0.2	0.3	0.015	0.02	0.024
12/09/99	1150	0.005	<0.001	<0.001	0.048	0.048	0.053	[5]0.1	[5]E 0.07	[5]E 0.1	0.011	0.016	0.019

[1]Calculated from the ammonia concentrations and pH, temperature, and an equilibrium constant (U.S. Geological Survey Office of Water Quality Technical Memorandum No. 93.12, 1993, URL http://water.usgs.gov/admin/memo/QW/qw93.12.html, accessed February 7, 2002).

[2]Nitrate plus nitrite minus nitrite.

[3]Calculated as the sum of dissolved ammonia and dissolved nitrate plus nitrite. See table 4.

[4]Calculated as the sum of total ammonia plus organic nitrogen and dissolved nitrate plus nitrite. See table 4.

[5]Based on variability in the laboratory method, there is no significant difference between the concentration of (1) dissolved ammonia plus organic nitrogen, (2) total ammonia plus organic nitrogen, and (3) total nitrogen (D.K. Mueller, U.S. Geological Survey, oral commun., 2002).

Table 38. Reservoir profile measurements, Crystal Reservoir near Crystal Dam (site CR1), April–December 1999

[Site number refers to table 1 and figure 1; C, Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)
APRIL 20, 1999, SECCHI-DISC DEPTH, 3.0 METERS					**AUGUST 24, 1999, SECCHI-DISC DEPTH, 5.5 METERS**				
1	5.1	10.3	8.2	215	1	15.5	8.6	8.4	193
2	5.0	10.3	8.2	215	2	15.5	8.6	8.4	193
3	5.0	10.2	8.2	213	3	15.5	8.6	8.4	195
4	5.0	10.2	8.2	215	4	15.4	8.6	8.4	193
5	4.9	10.2	8.2	214	5	15.4	8.6	8.4	193
6	4.8	10.2	8.2	211	6	15.1	8.6	8.4	194
7	4.7	10.2	8.2	214	7	15.0	8.6	8.4	193
8	4.6	10.1	8.2	213	8	14.0	8.9	8.3	195
9	4.5	10.2	8.2	214	9	11.6	8.5	8.1	189
10	4.5	10.2	8.2	212	10	11.4	8.4	8.0	191
11	4.4	10.1	8.2	212	11	11.1	8.2	7.9	195
12	4.4	10.1	8.2	214	12	10.9	8.2	7.9	196
13	4.4	10.1	8.2	214	13	10.8	8.1	8.0	194
14	4.5	10.1	8.2	213	14	10.7	8.1	7.9	193
15	4.4	10.1	8.2	213	15	10.7	8.1	7.9	194
16	4.4	10.1	8.2	212	16	10.7	8.1	7.9	193
17	4.4	10.1	8.2	212	17	10.6	8.1	7.9	191
18	4.4	10.1	8.2	214	18	10.5	8.0	7.9	190
19	4.4	10.1	8.2	214	19	10.4	8.0	7.9	188
20	4.4	10.1	8.2	215	20	10.4	8.0	7.9	189
25	4.4	10.1	8.2	215	25	10.3	7.9	7.9	191
30	4.4	10.0	8.2	217	30	10.2	7.8	8.0	193
35	4.3	10.1	8.2	219	35	10.0	7.5	8.0	196
					40	8.4	6.1	7.9	211
					45	6.1	4.9	7.7	239
					49.3	6.2	3.4	7.6	243

Table 38. Reservoir profile measurements, Crystal Reservoir near Crystal Dam (site CR1), April–December 1999—Continued

[Site number refers to table 1 and figure 1; C, Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Depth (meters)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)
OCTOBER 13, 1999, SECCHI-DISC DEPTH, 3.5 METERS					**DECEMBER 2, 1999, NO DATA FOR SECCHI-DISC DEPTH**				
1	11.3	7.4	7.4	186	1	6.0	9.0	7.3	188
2	11.2	7.4	7.4	185	2	6.0	8.8	7.3	187
3	11.1	7.4	7.4	185	3	6.0	8.9	7.3	188
4	11.1	7.4	7.4	185	4	6.0	8.9	7.3	187
5	11.1	7.4	7.4	185	5	6.0	8.8	7.3	187
6	11.1	7.4	7.4	185	6	6.0	8.6	7.3	187
7	11.1	7.4	7.4	185	7	6.0	8.7	7.3	188
8	11.1	7.3	7.4	185	8	6.0	8.8	7.3	188
9	11.1	7.3	7.4	185	9	6.0	8.8	7.3	188
10	11.1	7.3	7.5	186	10	6.0	8.5	7.3	187
11	11.1	7.3	7.6	185	11	6.0	8.6	7.3	187
12	11.1	7.3	7.6	185	12	6.0	8.6	7.3	188
13	11.1	7.3	7.5	185	13	6.0	8.5	7.3	188
14	11.1	7.2	7.5	185	14	6.0	8.5	7.3	188
15	11.1	7.3	7.5	185	15	6.0	8.5	7.3	188
16	11.1	7.3	7.5	185	16	6.0	8.6	7.3	188
17	11.1	7.2	7.5	185	17	6.0	8.5	7.3	188
18	11.1	7.2	7.5	185	18	6.0	8.5	7.3	187
19	11.1	7.3	7.5	185	19	6.0	8.5	7.3	187
20	11.0	7.2	7.5	185	20	6.0	8.4	7.3	187
25	11.0	7.2	7.5	185	25	6.0	8.5	7.3	187
30	11.0	7.2	7.5	185	30	6.0	8.4	7.3	189
35	11.0	7.2	7.4	185	35	6.0	8.4	7.4	188
40	10.9	7.0	7.4	183	40	6.0	8.4	7.4	188
44.4	10.5	3.2	7.2	184	45	6.0	8.5	7.4	192
					50	6.0	8.4	7.4	193
					52.8	6.0	8.0	7.2	196

Table 39. Nitrogen and phosphorus concentrations at Crystal Reservoir near Crystal Dam (site CR1), April–December 1999

[Site number refers to table 1 and figure 1; <, less than; E, estimated]

Date	Time	Sampling depth (feet)	Concentration, in milligrams per liter											
			Nitrogen, ammonia, dissolved	Nitrogen, un-ionized ammonia[1]	Nitrogen, nitrite, dissolved	Nitrogen, nitrate + nitrite, dissolved	Nitrogen, nitrate, dissolved[2]	Nitrogen, inorganic, dissolved[3]	Nitrogen, ammonia + organic, dissolved	Nitrogen, ammonia + organic, total	Nitrogen, total[4]	Ortho-phosphate, dissolved	Phos-phorus, dissolved	Phos-phorus, total
04/20/99	1530	2	0.003	<0.001	0.001	0.1	0.099	0.1	0.1	0.2	0.3	0.007	0.010	0.017
	1630	42	0.003	<0.001	0.001	0.1	0.099	0.1	0.1	0.1	0.2	0.007	0.009	0.017
08/24/99	0930	2	0.008	<0.001	0.001	<0.005	<0.005	0.009	0.2	0.2	0.2	<0.001	0.004	0.009
	1005	26	0.009	<0.001	0.001	<0.005	<0.005	0.010	0.2	0.2	0.2	<0.001	<0.004	0.02
	1055	175	0.01	<0.001	0.002	0.18	0.178	0.19	0.2	0.2	0.4	0.02	0.024	0.057
10/13/99	1150	2	0.004	<0.001	0.001	0.04	0.039	0.04	0.1	0.1	0.1	0.019	0.016	0.022
	1200	154	0.009	<0.001	0.001	0.044	0.043	0.053	[5]0.2	[5]0.1	[5]0.1	0.018	0.015	0.023
12/02/99	1235	2	<0.002	<0.001	<0.001	0.039	0.039	0.039	E 0.09	0.2	0.2	0.009	0.014	0.02
	1250	16	<0.002	<0.001	<0.001	0.041	0.041	0.041	E 0.06	0.1	0.1	0.009	0.014	0.02
	1305	170	0.003	<0.001	<0.001	0.044	0.044	0.047	<0.1	0.1	0.1	0.009	0.015	0.02

[1]Calculated from the ammonia concentrations and pH, temperature, and an equilibrium constant (U.S. Geological Survey Office of Water Quality Technical Memorandum No. 93.12, 1993, URL http://water.usgs.gov/admin/memo/QW/qw93.12.html, accessed February 7, 2002).

[2]Nitrate plus nitrite minus nitrite.

[3]Calculated as the sum of dissolved ammonia and dissolved nitrate plus nitrite. See table 4.

[4]Calculated as the sum of total ammonia plus organic nitrogen and nitrate plus nitrite. See table 4.

[5]Based on variability in the laboratory method, there is no significant difference between the concentration of (1) dissolved ammonia plus organic nitrogen, (2) total ammonia plus organic nitrogen, and (3) total nitrogen (D.K. Mueller, U.S. Geological Survey, oral commun., 2002).

Table 40. Number of phytoplankton detected at Crystal Reservoir near Crystal Dam (site CR1), April–December 1999

[Site number refers to table 1 and figure 1; Algal units/L, algal units per liter]

Phylum	Family	Genus	Algal units/L	Phylum	Family	Genus	Algal units/L
	April 20, 1999				**October 13, 1999**		
Bacillariophyta	Coscinodiscaceae	*Melosira*	87	Bacillariophyta	Coscinodiscaceae	*Melosira*	110
Bacillariophyta	Fragilariaceae	*Asterionella*	31	Bacillariophyta	Fragilariaceae	*Asterionella*	3
Bacillariophyta	Fragilariaceae	*Fragilaria*	24	Bacillariophyta	Fragilariaceae	*Fragilaria*	23
Bacillariophyta	Fragilariaceae	*Tabellaria*	35	Bacillariophyta	Fragilariaceae	*Tabellaria*	34
Bacillariophyta	Naviculaceae	*Navicula*	3	Cyanophyta	Nostocaceae	*Aphanizomenon*	5
Chrysophyta	Dinobryaceae	*Dinobryon*	3	Pyrrophyta	Ceratiaceae	*Ceratium*	3
	August 16, 1999				**December 2, 1999**		
Bacillariophyta	Coscinodiscaceae	*Melosira*	17	Bacillariophyta	Coscinodiscaceae	*Melosira*	151
Bacillariophyta	Coscinodiscaceae	*Stephanodiscus*	7	Bacillariophyta	Fragilariaceae	*Asterionella*	3
Bacillariophyta	Fragilariaceae	*Asterionella*	209	Bacillariophyta	Fragilariaceae	*Fragilaria*	3
Bacillariophyta	Fragilariaceae	*Fragilaria*	31	Bacillariophyta	Fragilariaceae	*Tabellaria*	18
Bacillariophyta	Naviculaceae	*Navicula*	70				
Chlorophyta	Chlorococcaceae	*Schroederia*	17				
Chrysophyta	Dinobryaceae	*Dinobryon*	14				
Pyrrophyta	Ceratiaceae	*Ceratium*	28				

Table 41. Physical properties and suspended sediment (inflows only) for Crystal Reservoir inflow and outflow sites, May–December 1999

[ft^3/s, cubic feet per second; C, Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; site number refers to table 1 and figure 1; --, no data; E, estimated]

Date	Time	Discharge (ft^3/s)	Width (feet)	Temperature (degrees C)	Dissolved oxygen (mg/L)	pH standard (units)	Specific conductance (µS/cm)	Suspended sediment (mg/L)
MORROW POINT RESERVOIR OUTFLOW								
05/27/99	--	[1]3,196	--	--	--	--	--	--
08/24/99	--	[1]2,135	--	--	--	--	--	--
10/07/99	--	[1]3,071	--	--	--	--	--	--
12/09/99	--	[1]1,109	--	--	--	--	--	--
MORROW POINT RESERVOIR DISCHARGE (SITE MO)								
05/27/99	0915	--	--	7.8	9.6	8.3	177	--
08/24/99	1310	--	--	9.9	8.2	7.7	175	--
10/07/99	1435	--	--	11.2	6.9	7.9	172	--
12/09/99	1150	--	--	6.0	12.0	8.1	182	--
MESA CREEK ABOVE CRYSTAL RESERVOIR, NEAR CIMARRON (SITE CI2)								
05/27/99	0935	36.0	16.0	6.2	9.4	7.7	48	9
08/24/99	1420	E 0.41	--	16.8	7.7	8.2	131	4
10/07/99	1345	E 0.19	--	8.6	9.1	8.2	143	3
12/09/99	1215	E 0.18	--	0.0	11.5	8.1	130	2
CRYSTAL CREEK AT HIGHWAY 92, NEAR CRAWFORD (SITE CI3)								
05/24/99	1400	3.10	12.0	16.8	7.2	8.3	227	5
08/26/99	0930	0.11	1.70	14.6	7.8	8.1	413	1
10/14/99	0925	0.11	2.10	3.2	8.9	8.0	444	1
12/07/99	0900	0.16	2.20	0.0	7.8	7.8	422	3
CIMARRON RIVER BELOW SQUAW CREEK, NEAR CIMARRON (SITE CI4)								
06/03/99	1130	194	43.0	10.0	9.1	8.2	266	133
08/10/99	0845	97.0	30.0	13.0	7.9	8.2	449	56
10/07/99	1130	75.0	26.0	8.2	9.9	8.4	391	16
12/09/99	0925	26.0	28.0	0.0	11.5	8.3	413	2
CRYSTAL RESERVOIR OUTFLOW								
05/26/99	--	[1]3,824	--	--	--	--	--	--
08/24/99	--	[1]2,044	--	--	--	--	--	--
10/13/99	--	[1]1,726	--	--	--	--	--	--
12/02/99	--	[1]1,209	--	--	--	--	--	--
GUNNISON RIVER BELOW GUNNISON TUNNEL (SITE CO)								
05/26/99	1315	--	122	8.6	9.6	8.4	188	--
08/24/99	1340	--	108	11.5	8.6	9.0	195	--
10/13/99	0930	--	110	11.0	8.5	8.0	187	--
12/02/99	1225	--	--	6.5	9.7	8.3	186	--

[1]Mean value for the day.

Table 42. Nitrogen and phosphorus concentrations in Crystal Reservoir inflow and outflow sites, May–December 1999

[Site number refers to table 1 and figure 1; <, less than; E, estimated]

Date	Time	Concentration, in milligrams per liter											
		Nitrogen, ammonia, dissolved	Nitrogen, un-ionized ammonia, dissolved[1]	Nitrogen, nitrite, dissolved	Nitrogen, nitrate + nitrite, dissolved	Nitrogen, nitrate, dissolved[2]	Nitrogen, inorganic, dissolved[3]	Nitrogen, ammonia + organic, dissolved	Nitrogen, ammonia + organic, total	Nitrogen, total[4]	Ortho-phosphate, dissolved	Phos-phorus, dissolved	Phos-phorus, total
MORROW POINT RESERVOIR DISCHARGE (SITE MO)													
05/27/99	0915	0.004	<0.001	0.001	0.01	0.009	0.01	0.1	0.2	0.2	0.006	0.007	0.034
08/24/99	1310	0.02	<0.001	0.005	0.051	0.046	0.07	0.1	0.2	0.3	0.012	0.016	0.022
10/07/99	1435	<0.002	<0.001	0.001	0.063	0.062	0.063	0.1	0.2	0.3	0.015	0.02	0.024
12/09/99	1150	0.005	<0.001	<0.001	0.048	0.048	0.053	[5]0.1	[5]E 0.07	[5]E 0.1	0.011	0.016	0.019
MESA CREEK ABOVE CRYSTAL RESERVOIR, NEAR CIMARRON (SITE CI2)													
05/27/99	0935	0.006	<0.001	0.001	0.094	0.093	0.100	0.2	0.3	0.4	0.011	0.019	0.048
08/24/99	1420	0.016	<0.001	0.001	0.058	0.057	0.074	0.2	0.4	0.5	0.034	0.039	0.045
10/07/99	1345	0.003	<0.001	0.001	0.028	0.027	0.031	0.1	0.1	0.1	0.028	0.033	0.041
12/09/99	1215	<0.002	<0.001	0.001	0.079	0.078	0.079	[6]E 0.09	[6]E 0.07	E 0.1	0.022	0.028	0.031
CRYSTAL CREEK AT HIGHWAY 92, NEAR CRAWFORD (SITE CI3)													
05/24/99	1400	0.005	<0.001	0.001	0.007	0.006	0.012	0.5	0.6	0.6	0.04	0.05	0.069
08/26/99	0930	0.031	0.001	0.004	0.014	0.010	0.045	0.4	0.5	0.5	0.047	0.057	0.073
10/14/99	0925	0.011	<0.001	0.001	0.005	0.004	0.016	0.2	0.3	0.3	0.025	0.025	0.036
12/07/99	0900	<0.002	<0.001	0.001	<0.005	<0.005	<0.005	0.3	0.3	0.3	0.019	0.025	0.027
CIMARRON RIVER BELOW SQUAW CREEK, NEAR CIMARRON (SITE CI4)													
06/03/99	1130	0.01	<0.001	0.002	0.03	0.028	0.04	0.3	0.6	0.6	0.036	0.043	0.17
08/10/99	0845	0.006	<0.001	0.001	0.056	0.055	0.062	[6]0.2	[6]0.1	0.2	0.052	0.063	0.13
10/07/99	1130	<0.002	<0.001	0.001	0.037	0.036	0.037	0.2	0.3	0.3	0.026	0.034	0.065
12/09/99	0925	0.005	<0.001	0.002	0.17	0.168	0.18	E 0.09	0.1	0.3	0.021	0.031	0.035
GUNNISON RIVER BELOW GUNNISON TUNNEL (SITE CO)													
05/26/99	1315	0.005	<0.001	0.001	0.013	0.012	0.018	0.1	0.4	0.4	0.007	0.009	0.045
08/24/99	1340	0.004	<0.001	<0.001	0.037	0.037	0.041	[5]0.2	[5]0.1	[5]0.1	0.012	0.013	0.07
10/13/99	0930	<0.002	<0.001	0.001	0.034	0.033	0.034	0.1	0.1	0.1	0.01	0.015	0.022
12/02/99	1225	<0.002	<0.001	<0.001	0.083	0.083	0.083	<0.1	0.1	0.2	0.015	0.021	0.027

[1]Calculated from the ammonia concentrations and pH, temperature, and an equilibrium constant (U.S. Geological Survey Office of Water Quality Technical Memorandum No. 93.12, 1993, URL http://water.usgs.gov/admin/memo/QW/qw93.12.html, accessed February 7, 2002).

[2]Nitrate plus nitrite minus nitrite.

[3]Calculated as the sum of dissolved ammonia and dissolved nitrate plus nitrite. See table 4.

[4]Calculated as the sum of total ammonia plus organic nitrogen and dissolved nitrate plus nitrite. See table 4.

[5]Based on variability in the laboratory method, there is no significant difference between the concentration of (1) dissolved ammonia plus organic nitrogen, (2) total ammonia plus organic nitrogen, and (3) total nitrogen (D.K. Mueller, U.S. Geological Survey, oral commun., 2002).

[6]Based on variability in the laboratory method, there is no significant difference between the concentration of (1) dissolved ammonia plus organic nitrogen and (2) total ammonia plus organic nitrogen (D.K. Mueller, U.S. Geological Survey, oral commun., 2002).